DISH EVERYWHERE: STUDY OF THE PATHOGENESIS OF DIFFUSE IDIOPATHIC SKELETAL HYPEROSTOSIS AND OF ITS PREVALENCE IN ENGLAND AND CATALONIA FROM THE ROMAN TO THE POST-MEDIEVAL TIME PERIOD.

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DISH Everywhere: Study of the Pathogenesis of Diffuse Idiopathic Skeletal Hyperostosis and of its Prevalence in England and Catalonia from the Roman to the Post-Medieval Time Period.

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ABSTRACT

Diffuse idiopathic skeletal hyperostosis (DISH) is a spondyloarthropathy traditionally defined as having spinal and extra-spinal manifestations. However its diagnostic criteria only allow the identification of advanced DISH and there is little consensus regarding the extra-spinal enthesopathies. In this project, individuals with DISH from the WM Bass Donated Skeletal Collection were analysed to investigate the pathogenesis of DISH and archaeological English and Catalan samples (3rd–18th century AD) were studied to investigate how diet might have influenced the development of DISH.

From the individuals from the Bass Collection, isolated vertical lesions representing the early stages of DISH ('early DISH') were identified. Both sample sets showed that the presence of extra-spinal manifestations varies significantly between individuals and that discarthrosis and DISH can co-exist in the same individual.

In all archaeological samples, the prevalence of DISH was significantly higher in males and older individuals showed a higher prevalence of DISH. In both regions, the prevalence of DISH was the lowest in the Roman samples, the highest in the early medieval ones and intermediate in the late medieval samples. While when using documentary resources and archaeological data, it was hypothesised that the prevalence of DISH in the English and Catalan samples might have been different, the results show no significant differences even if English samples tend to show higher prevalence of DISH than the Catalan samples. This possibly suggests that the development of DISH depends on a combination of dietary habits and, possibly, genetic predisposition might influence the development of DISH.

The individuals from the Bass Collection showed high prevalence of metabolic and cardiovascular conditions. In contrast, no association was found between DISH and rich-diet associated conditions (e.g. carious lesions and gout) or deficiency-related conditions (e.g. scurvy, healed rickets).

Key words: Diffuse idiopathic skeletal hyperostosis (DISH), early diagnosis, Roman period, early medieval period, late medieval period, post-medieval period, English diet, Catalan diet

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Abbreviations

Bass Collection: WM Bass Donated Skeletal Collection located at the Anthropology Department at the University of Tennessee (Knoxville, TN)

DDD: degenerative disc disease

DISH: diffuse idiopathic skeletal hyperostosis

pre-DISH: stages 1 and 2 of DISH development as described in Table 18 (Section B.2.3.3)

DM: diabetes mellitus

ESM: extra-spinal manifestations associated to DISH

OA: osteoarthritis

C1 – 7: cervical vertebrae 1 to 7

T1 – 12: thoracic vertebrae 1 to 12

L1 – 5: lumbar vertebrae 1 to 5

1. INTRODUCTION

1.1 Background

Diffuse idiopathic skeletal hyperostosis (DISH) is a well-known spondylarthropathy frequently reported in archaeological human remains and in the medical clinical literature. In clinical medicine as well as in palaeopathology, DISH has traditionally been related to male individuals over 50 years of age and it has been noted that the prevalence of DISH increases with increasing age (Julkunen et al. 1971; Henrard and Bennett 1973; Resnick et al. 1975; Jankauskas 2003; Kacki and Villotte 2006; Holton et al. 2011). While significant symptoms are rarely experiences in DISH, the total absence of symptoms in early DISH results in a delayed diagnosis in modern medicine and in a lack of understanding of the onset of this disease. Indeed, none of the existing diagnostic criteria allows for the positive diagnosis of DISH before 3 or 4 vertebrae are completely fused (e.g. Resnick and Niwayama 1976; Rogers and Waldron 1995). Furthermore, as these diagnostic criteria are not directly comparable (van der Merwe et al. 2012), the comparison of the results obtained from different studies is very complicated.

Clinically, DISH has been correlated to metabolic-related conditions and derangements (e.g. obesity and gout) possibly linked to highly calorific diet, which, in the archaeological context, have been associated with monastic life and to high status individuals (Julkunen et al. 1971; Littlejohn and Hall 1982; Waldron 1985; Daragon et al. 1995; Jankauskas 2003; White 2004; Mader and Lavi 2009; Hart and Holbrook 2011; Holton et al. 2011; Kim et al. 2012; Wilczak and Mulhern 2012).

To address these problems, the following questions should be researched:

1. Is it possible to identify early DISH? What are its main features?
2. Are the extra-spinal manifestations characteristic enough to be included in the diagnostic criteria?
3. Has the prevalence of DISH changed through time? And what might have influence this change?
4. Does the prevalence of DISH change between regions? And what might have influenced this difference?

1.2 Aims and objectives of this research

Questions 1 and 2 need to be explored via the known cases of DISH from the WM Bass Donated Skeletal Collection. The aim of the first part of the project is to identify the early stages of DISH, explore the relationship between the spinal and the extra-spinal manifestations of the condition and analyse the prevalence of diet-related or metabolic conditions in DISH individuals. The specific objectives are:

- Evaluate the development of the spinal manifestation of the disease in cases of DISH from the WM Bass Donated Skeletal Collection previously diagnosed by the resident osteologists from the Department of Anthropology of the University of Tennessee.
- Examine the relationship between the development of the extra-spinal and the spinal manifestations in individuals positively diagnosed with DISH.

Question 3 and 4 will be explored by analysing English and Catalan samples dating from the Roman to the post-medieval period. The aim of the second part of this project is to investigate how life-style and diet might affect the prevalence of the condition in the different populations. The objectives are as follows:

- Describe the demographic profiles of the different English and Catalan populations in study.
- To identify the individuals of each period and geographical area with DISH.
- Compare the prevalence of DISH between English and Catalan populations during a specific historic period.
- Study the demographic profile of DISH for both geographical areas throughout and identify which age groups are affected in each case.
- Macroscopically, evaluate the co-morbidity of DISH with other metabolic conditions (gout, dental pathologies, osteoarthritis, rickets and osteomalacia, scurvy and enamel hypoplasia)
- Applying stable isotope analysis on dental and bone collagen, compare the dietary characteristics of the individuals with versus the individuals without DISH.

The choice of the different time periods has been done so the analysis will allow the creation of a diachronic picture of the prevalence of DISH. The region of England was chosen because of the availability of archaeological sites covering all the time periods at the University of Bradford. In contrast, the area of Catalonia was chosen firstly because it is an area where bioarchaeological research is very scant so this research would increase the amount of data available. Secondly because this area is characterised by having a Mediterranean diet, very different from the traditional English diet, which might have an influence on the prevalence of DISH in this area.

1.3 Thesis structure

The ultimate aim of this project was to gain a clearer understanding of what diffuse idiopathic skeletal hyperostosis is. As previously indicated, this will be explored through two sets of aims and objectives which, in their turn, have dictated the structure of this thesis. The first part of the thesis (Part A) will deal with the investigation of DISH itself through the analysis of the individuals with DISH from the WM Bass Donated Skeletal Collection. The results and discussion of Part A will inform the second part of this thesis (Part B). Part B deals with the investigation on how the prevalence of DISH might have changed through time in England and Catalonia and which are the factors that might have influenced this change. Thus both parts of the thesis will contain their respective introduction, methods, results, discussion and conclusions.

2. DESCRIPTION OF DIFFUSE IDIOPATHIC SKELETAL HYPEROSTOSIS (DISH)

Diffuse idiopathic skeletal hyperostosis (DISH) is a systemic hyperostotic condition characterised by the ossification of, or next to, ligaments and tendons (Mader et al. 2013). The most common manifestations are a 'flowing' ossification at the antero-lateral portion of the spinal column and extraspinal enthesopathies (Figures 1 and 2) (Resnick et al. 1975; Utsinger 1985; Crubézy 1989).

Figure 1 (above): Extra-spinal manifestation of DISH (arrow). The calcaneal tuberosity shows a prominent enthesopathy at the insertion of the Achilles tendon in individual 520 from Gambier Parry Lodge (G 9/83 W, University of Bradford) (source: author).

Figure 2 (left): Spinal manifestation of DISH. This thoracic vertebrae shows the characteristic 'flowing' ossification at the right side of the vertebral body. Individual 361 from Chichester (University of Bradford). (source: author).

The first references to DISH can be attributed to Knaggs (1925), Meyer and Forster (1938) and Oppenheimer (1942) who described a condition characterised by extensive ossification of the vertebral ligaments which was most extensive at the anterior longitudinal ligament of the thoracic region, less complete at the lumbar vertebrae and almost always absent in the cervical segment. Knaggs (1925) named it *spondylitis deformans* and Oppenheimer (1942), *spondylitis ossificans ligamentosa.*

Oppenheimer (1942) also suggested that the ossification of the ligament was dependent on the disuse related to vertebral immobility and rarefaction of the adjacent bone. Oppenheimer (1942) proposed that immobility increased the probability of transforming the undifferentiated connective tissue into bone and that the deposits in the new bone originated from the rarefied vertebral body. Following this logic, the ligamentous ossification was not a pathology in itself but a secondary phenomenon.

In 1955, Smith and colleagues described the spinal ossification as *physiologic vertebral ligamentous calcification*. Similarly to the previous descriptions, they also reported that the vertebral abnormalities were more common in the thoracic spine and included the ossification of the anterior longitudinal ligament up to a thickness of 5 to 10 mm, osteophytes and absence of osteoporosis. The authors also noted that the ossification appeared increased in thickness at the level of the intervertebral disc and was distinct of the anterior margins of the adjacent vertebrae and observed that sacroiliac, apophyseal and costovertebral joints appeared normal in the majority of the patients. Thus it was argued that all these changes had to do with the degenerative changes related to the age of the patients since all their patients with the disease were over 60 years of age (Smith et al. 1955).

Sutro and colleagues (1956) were the first to describe radiographic abnormalities observed in the axial and the extra-axial skeleton. They found no symptomatic correlation and concluded that the abnormalities did not seem to restrict mobility and thus were considered to be part of a systemic condition thus naming it as *generalised juxta-articular ossification of ligaments of the vertebral column.*

The first diagnostic criterion belonged to Forestier and Rotés-Querol who in 1950 described the radiographic appearance as:

> *"Bony outgrowths of hyperostosis, mainly at the dorsal region, arising from the anterolateral aspect of the vertebral bodies and growing upwards in a "candle-flame" formation over the lumbar disk spaces; at the level of the dorsal disks they are often thickened. They have a bony structure with a dense cortex similar to that of the head of the femur, the cancellous bone being in continuity with that of the vertebral bodies. They may co-exist with osteophytes, but have entirely different anatomical features"* (Forestier and Rotes-Querol 1950: 5).

They named it *senile ankylosis hyperostosis of the spine* though it would be commonly known as *Forestier's disease* (Rogers and Waldron 1995). Forestier and Rotés-Querol (1950) indicated that while the aetiology was unknown, old age was a common feature in all the patients and half of them had also suffered from a severe trauma which they suggested could precipitate the clinical signs. However most importantly, they pointed out that the spinal ossification did not come from the anterior vertebral common ligament (also known as anterior longitudinal ligament) and proposed that the spinal ossification arose from the continuous peri-vertebral fibrous sheath. This involvement of ligaments and connective paravertebral tissue in the formation of the spinal lesion led Forestier and Lagier (1971) to describe them as *entheseal*, a nomenclature also used by François et al. (1995), Freemont (2002) and Hannallah et al. (2007). However, nowadays, the majority of the osteaorchaeology research community still refer them as DISH-ostephytes as they were descrived by Resnick and Niwayama (1976).

Previous studies had noted that the spinal manifestations were accompanied with extra-spinal enthesopathies (Sutro et al. 1956; Harris et al. 1974), however the first systematic analysis on the type and location of the extra-spinal abnormalities were authored by Resnick, Shaul and Robins in 1975. The authors noted that the most common sites for the entheseal abnormalities to be found were the pelvis, calcaneus and tarsals, olecranon and patella. Because of the diffuse distribution and the hyperostotic character of the manifestations, the authors named the condition as *diffuse idiopathic skeletal hyperostosis* (DISH) which is the name now preferred by the scientific and clinical communities (François et al. 1995; Resnick 2002: 1477).

Nowadays, in the clinical sphere, the relationship between the spinal and the extra-spinal manifestations is still being discussed, extra-spinal manifestations are not consistently included in all diagnostic criteria and attempts at creating a new diagnostic criteria have shown that experts still disagree in the relationship between these two manifestations (Mader et al. 2012, Kuperus et al. 2017). And yet, from an osteoarchaeological point of view, the association of the spinal and the extra-spinal manifestations has not been investigated and, to the understanding of the author, DISH is still considered a pathology characterised by spinal ossification and extra-spinal enthesopathy.

PART A: IDENTIFICATION OF THE EARLY STAGES OF DISH

A.1. DISH IN MODERN CLINICAL PRACTICE

This chapter provides a summary of what it is known about DISH in the clinical setting. First, there is a summary of the DISH epidemiology in different populations followed by an evaluation of the different diagnostic criteria and the difficulties that arise from their different considerations. Finally, the attempts to explore the aetiology of this condition and the complications derived from DISH are described.

A.1.1 Epidemiology

There seems to be a general consensus that DISH affects primarily men over 50 years of age and there is an increase of the prevalence with age (Julkunen et al. 1971; Maat et al. 1995; Mata et al. 1997; Weinfeld et al. 1997; Hannallah et al. 2007) however no significant difference in the prevalence of DISH between sexes were found in the Turkish population (Sencan et al. 2005). Nevertheless, it is widely regarded that this prevalence may continue increasing in the coming decades because of the association between DISH and life-style related risk factors such as obesity and Type II diabetes mellitus (see section A.1.3) (Kiss et al. 2002b; Denko and Malemud 2006).

Table 1 corresponds to reports on modern populations. It is important to notice the great variability in the application of the methods as well as the age group scrutinised in each study. Nonetheless, all the studies show an increase of the prevalence of DISH in older individuals (Julkunen et al. 1971; Tsukamoto et al.

1977; Cassim et al. 1990). And all the studies also show a higher prevalence in males than in females, however most studies also show that the difference in prevalence between males and females is reduced in the older age groups.

Finally some researchers have found differences in the prevalence of DISH in different ethnicities. Some studies have reported that the prevalence of the condition was significantly lower in black, Native-Americans and Asian populations compared to the white population (Weinfeld et al. 1997; Resnick 2002: 1476-1503). However another study reported that the prevalence of DISH in the African black population of South Africa was very similar than other European, North American and Asian populations (Cassim et al. 1990). DISH seems to be much more prevalent in Pima Indians living in Arizona as 25% of the male and 4.7% of the female population over the age of 15 suffered the disease and at the age of 55 and older, the prevalence had increased to 48% and 12% in Pima males and females respectively (Henrard and Bennett 1973).

Table 1: Prevalence of DISH in modern populations

Reference	Country	Sample size	Diagnostic Criteria	Age range	Prevalence (%)*		
					Male	Female	Pop. Average
Julkunen et al. (1971)	Finland	12,585	Forestier and Rotés-Querol (1950)	<50	0.3	0.2	
				50-59	2.7	1.7	
				60-69	8.4	4.3	
				>70	11.2	6.9	
Tsukamoto et al. (1977)	Japan	20.000	NS	40-49	0.6	0.3	
				50-59	7.1	0.9	
				60-69	12.4	1.1	
				>70	12.5	0	
Cassim et al. (1990)	South Africa	1000	Resnick and Niwayama (1976)	40-49	1.3	0	
				50-59	4.2	1	
				60-69	4.2	6.8	
				70+	14.3	12	
Kiss et al. (1997)	Hungary	NS	NS	>50	5.8	1.3	
Weinfield et al. (1997)	Minnesota (USA)	2364	NS	>50	25	15	
				71-80	38	-	
				81-90	28	26	
Kiss et al. (2002b)	Hungary	635	NS	>40	10	1.9	
				>70	35.5	25.6	
Kiss et al. (2002a)	Hungary	NS	Resnick modified criteria	50-54	10	1.9	
				>75	36	26	
Sencan et al. (2005)	Turkey	266	NS	42-67	12.9	7.2	
Westerveld et al. (2009)	Netherlands	501	NS	>50			17.0
Diederichs et al. (2011)	USA	342	Mata et al. (1998)	65+	52		
			Resnick et al. (1975)		38		

*All prevalence values are indicated as reported in the original articles. NS: not specified. Pop. Average: average of DISH within the studied population

A.1.2 Evaluation and critique of the clinical diagnostic criteria

A.1.2.1 Discrepancies between different diagnostic criteria

When calculating the prevalence of DISH within a population or when comparing its prevalence between different populations, two things need to be considered: Firstly, there is not a standardised diagnostic criteria (see Table 2). Many authors use the original Resnick and Niwayama (1976) criteria (e.g. Hendrix et al. 1994; Kiss et al. 2002a; Kiss et al. 2002b; Sarzi-Puttini and Atzeni 2004) however its application is not universal. Since it has been demonstrated that different methods produce statistically different prevalence rates when applied on the same population (Resnick and Niwayama 1976; Diederichs et al. 2011; van der Merwe et al. 2012), the direct comparison between the prevalence rates obtained for the different populations is not possible. Furthermore, in a Delphi study by Mader and colleagues (2012)[1], the researchers found little consensus amongst the clinicians and orthopaedic surgeons on the features that should be included in a new diagnostic criteria; in fact, only the exuberant bone formation and the enlarged bony bridges in the spine reached a general consensus. The authors suggested that this significant discrepancy could be related to the contrasting results yielded by different directed studies (Mader et al. 2012).

Second, the florid hyperostosis that characterises DISH takes a lengthy period to develop and it has been suggested that the onset of the condition might be between the second and the fourth decade (Resnick 2002: 1478; Mader 2008; Mader and Lavi 2009). However Kuperus et al. (2017) reported that most of the

[1] A Delphi study is a survey method to investigate the level of consensus between experts. In Mader's et al. (2012) study, clinicians were submitted to a series of questionnaires to obtain the core features considered to characterise DISH.

diagnostic criteria did not consider that DISH is, in fact, a progressive condition and highlighted the complete lack of consensus around the identification of the early stages of the condition since these lesions are very complicated to identify in medical imaging. Since in most cases only individuals above the 50 years old mark are included in the research, the possibility of identifying the condition at an earlier stage has not been explored. Furthermore, as can be observed in the table below, most criteria need at least three or four vertebrae ankylosed to issue a definitive diagnosis. In fact, Resnick and Niwayama suggested, already in 1976, that the advanced age of the patients with DISH reflected not that the disorder has its inception in elderly patients but rather that a lengthy period of development is necessary before the spinal abnormalities progress to such a degree that they fulfil specific radiographic criteria. They even noted some patients between 20 to 40 years of age occasionally demonstrated radiographic features strongly suggestive of DISH although they did not fulfil the criteria. The choice of this threshold of four ankylosed vertebrae is arbitrary but it was set with the aim to separate DISH from typical spondylitis deformans (also known as spondylosis deformans or discarthrosis (François et al. 1995) which typically does not show ankylosis. Indeed, a lower threshold of two or three affected contiguous vertebrae could have been selected, which would have increased the prevalence of the disease (Resnick et al. 1978: 155). However since there was not enough evidence to prove which were the earlier expressions of the disease and whether these were completely exclusive of DISH, this high threshold has been maintained.

The existence of so many (and not totally equivalent) diagnostic criteria reflects the complexity of defining a diagnostic criteria for DISH that would include the spinal and the extra-spinal manifestations. Thus the prevalence of this condition in historic and modern populations is, in fact, unknown (Mader 2008).

Table 2: Summary of the characteristics of the different diagnostic criteria for DISH in clinical medicine

		Resnick & Niwayama (1976)	Arlet & Maziéres (1985)	Utsinger (1985)
	Criteria based on	Finds in X-rays	Finds in X-rays	Finds in X-rays
Spinal	Antero-lateral flowing ossification	Yes	Yes	Yes
	Ankylosis discontinuity[a]	Yes	n/a	Yes
	Unilateral	Yes	n/a	n/a
	Definitive DISH[b]	≥4 in thoracic	≥3 in low thoracic	≥4 in thoraco-lumbar
	Prob./poss. DISH[c]	3 in thoracic	2 in low thoracic	2 (thoracic)
	Cervical involvement	n/a	Yes[d]	n/a
	Lumbar involvement	n/a	Yes[d]	n/a
	Apophyseal joint	Preserved	Preserved	Preserved
	Intervert. disc space	Retained	Retained	Retained
	Discarthrosis	No	No	Yes[d]
	Sacroiliac joint	Unaffected	Unaffected	n/a
Extra-spinal	Enthesophytosis	n/a	n/a	Yes
	Presence	n/a	n/a	Bilateral
	Patella tufting	n/a	n/a	Yes
	Heel spurs	n/a	n/a	Yes
	Olecranon tufting	n/a	n/a	Yes
	Tibial tub. Spurs	n/a	n/a	n/a
	Lig. flavum ossif.	n/a	n/a	Yes
	Sacroiliac lig. ossif.	n/a	Yes[d]	n/a
	Iliolumbar lig. ossif.	n/a	Yes[d]	n/a

The shaded features are the ones which are shared amongst all the criteria. n/a: non-applicable: the diagnostic criterion does not mention this parameter. [a]: the criteria accepts that some bone bridges might not be completely fused. [b]: number of vertebrae required to issue a definitive diagnosis of DISH. [c]: number of vertebrae required to issue a probable or possible diagnosis of DISH [d]: the criteria observes the possibility of the feature to happen.

A.1.2.2 Problems with the extra-spinal manifestations

Most of the clinical diagnostic criteria do not include the extra-spinal manifestations however several studies have mentioned their presence. For example Harris and colleagues (1974) noted that of the 34 individuals included in their study, 24 complained of pain in the peripheral joins, mainly in the shoulders, knees, hips, feet and ankle and hands. Sutro et al. (1956) also reported that their patients referred minimal complaints; occasionally citing the presence of local pain or discomfort related to masses at the plantar fascia and the Achilles tendon.

These accounts predate Resnick and colleagues' (1975) ground-breaking report that 8 of the 21 patients (38%) who had been diagnosed with DISH had peripheral musculoskeletal complaints and that, in half of them, these symptoms were the initial finding before the spinal ankylosis. For those affected, the main locations of pain were shoulders, knees, elbows and heels and in all cases, the pattern of musculoskeletal symptoms was non-inflammatory. In the group of 40 patients with DISH from a university hospital who were seen and followed by a rheumatology service showed extra-spinal manifestations involved shoulders, hips, knee, and ankle and an aching pain, accentuated by rest and/or exercise, was characteristic (Resnick et al. 1975).

More recent reports suggest that the inclusion of these manifestations in the diagnostic criteria might not be as straight forward as the previous reports seemed to indicate. For example, in a methodological review of the different diagnostic criteria for DISH, Kuperus and colleagues (2017) found that out of the 24 articles analysed, only 5 included peripheral manifestations as a co-requirement for the diagnosis of the condition. These findings are in agreement with those reported by Mader and colleagues (2012) where seven rheumatologists and an orthopaedic surgeon reached no consensus regarding the inclusion of the extra-spinal manifestations in a new classification of DISH.

A.1.3 Aetiology and molecular mechanisms involved.

The aetiology of DISH has been under much debate since the condition was first described. Different studies have identified various possible aetiologies, however the results are often contradictory and there is not a major consensus about the underlying cause of this extensive bone hyperostosis. So far, DISH has been closely related to metabolic derangements, constitutional and cardiovascular conditions, vitamin A toxicity and it has been suggested to be genetically determined. The studies exploring the relation between these conditions and DISH are here further discussed. A medical glossary can be found at Appendix 1.

A.1.3.1. Metabolic and constitutional conditions

The relationship between diabetes mellitus (DM) and DISH has been under significant scrutiny but the results are, in many cases, contradictory. Littlejohn and Smythe (1981) reported a significant hyperinsulinaemia (presence of excess insulin in blood) in patients with DISH when compared to control patients. This was supported by el Miedany and colleagues (2000) who reported that 60% of their DISH patients were diabetic (n=40) and by Westerveld et al. (2014), who noted that DISH patients had, more frequently, a history of DM. In this same line, Mader and Lavi (2009) studied patients diagnosed with DISH before the 5th decade and after the 6th decade and compared them to a control group diagnosed with osteoarthritis (OA). Their results showed that the DISH patients were more likely to have a first degree relative with DM and were more likely to develop the condition during the follow-up, suggesting a relationship between these two conditions. Furthermore, other studies found that DISH patients had, characteristically, marked hyperinsulinaemia (Kiss et al. 2002b, Sarzi-Puttini and Atzeni 2004). Finally, Kiss et al. (2002b) argued that the hyperinsulinaemia related to obesity could be the linking metabolic parameter with the development of DISH.

In contrast, in a controlled study comparing DISH versus healthy patients, Daragon and colleagues (1995) found no differences in the glucoregulation (regulation of glucose metabolism) between the groups and concluded that there is no relationship between DISH and DM. This was further supported by Diederichs et al. (2011) and Sencan et al. (2005). Interestingly, the study by Eckertova and colleagues (2009) further confirms the absence of elevated serum glucose, insulin and lipid parameters in patients with DISH when age and BMI (body mass index) matched controls are used for comparison. However, their results show that DISH patients have decreased glucose-dependant insulin secretion and increased insulin clearance which could eventually lead to diabetes.

Beyond DM and glucose and insulin-related imbalances, DISH has been related to hyperuricaemia, dyslipemia and cholesterolemia (presence of cholesterol in blood) (el Miedany et al. 2000; Kiss et al. 2002b; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Miyazawa and Akiyama 2006) suggesting that DISH patients are commonly affected by metabolic imbalances (Utsinger 1985). For example, in a matched control study, Vezyroglou et al. (1996) found that DISH patients had a significant higher prevalence of DM combined with dyslipidemia (abnormal concentrations of lipids or lipoproteins in the blood) and hyperuricaemia (excess of uric acid in blood) than the control group suggesting that metabolic disturbances were more prevalent in the DISH patients. Growth hormone and insulin-like growth factors have also been examined in patients with DISH for their possible relation to diabetes; the studies have yielded contradictory results (see for example Denko and Malemud (2006) and Sencan et al. (2005)).

If the relation between diabetes mellitus and DISH is still not clear, at least the link between obesity or high BMI and DISH has been widely recognised since this condition was described (Forestier and Rotes-Querol 1950; Utsinger 1985; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Diederichs et al. 2011). Obesity has been suggested to be an aetiological factor for DISH (Daragon et al. 1995). El Miedany et al. (2000) reported that 50% (of 40 patients with DISH) were obese and Mader and Lavi (2009) reported that patients with DISH diagnosed before 50 years of age were significantly more likely to be obese compared to the control group. In a study aimed at evaluating the outcomes of traumatic spinal fractures in individuals with DISH compared to control patients, Westerveld and colleagues (2014) found that DISH patients were more frequently obese. Individuals with DISH group were also found to be significantly heavier and had a greater body lipid index than patients with spondylosis (Miyazawa and Akiyama 2006). Interestingly, it has been suggested that obesity at young age might also be related to the appearance of DISH (Mata et al. 1997, Kiss et al. 2002b).

Another metabolic finding that has raised discrepant results is hypertension (abnormally high arterial blood pressure). 22% of Utsinger's (1985) patients with DISH were hypertense while 16% of the control patients had hypertension. El Miedany and colleagues (2000) reported that 45% of their patients with DISH (n=40) were hypertensive and Mader and Lavi (2009) also showed that patients with DISH diagnosed before 50 or after 60 were significantly more likely to have a first degree relative with hypertension compared to a control group suggesting a relationship between these two conditions. However, Kiss et al. (2002b) found no difference between the DISH patients and the control group.

From all these studies, it seems that DISH is related to metabolic imbalances, however the results are rather confusing and contradictory. This suggest that DISH is a complex condition that might have more than one aetiological factor. It should also be taken into account that the co-morbidity of DISH and diabetes or hypertension, might also be caused by the sharing of a common risk factor, for example, obesity.

A.1.3.2 Cardiovascular aetiology

In 2000, El Miedany and colleagues suggested that DISH could be related to or a condition derived from the vascular system since they found an increased number and size of nutrient foramina in the ossified ligaments and vertebrae involved in the ankyloses. The authors also found that 45% of the patients with DISH had manifestations of ischaemic heart disease.

The relationship between the cardiovascular system and DISH has also been highlighted by Mader et al. (2005) who reported that patients with DISH were more likely to be admitted in the hospital with multiple conditions and because of an atrial fibrillation (very rapid uncoordinated contractions of the atria of the heart resulting in a lack of synchronism between heartbeat and pulse beat) and of left ventricular hypertrophy (excessive development of the left ventricle of the heart). This was supported by Denko and Malemud (2006) who also suggested that coronary artery disease was a risk factor for DISH. More recently, Westerveld et al. (2014) found that 23% of the patients with DISH also had cardiovascular disease. And Miyazawa and Akiyama (2006) coincided that DISH was associated with increased incidence of stroke and cerebrovascular disease compared to control group.

The latest results show that there might also be a close relationship between DISH and the cardiovascular system, however, as Miyazawa and Akiyama (2006) pointed out, the increased risk of stroke in DISH patients could also be related to the increased uraemia (accumulation in the blood of constituents normally eliminated in the urine) and diabetes or obesity, which also risk factors for stroke. Further studies are needed to elucidate the characteristics of this relationship.

A.1.3.3 Use of retinoids

Vitamin A derivatives (isoretinoin, etretinate and bexarotene) have been and still are prescribed for dermatological diseases such as acne, psoriasis and skin cancer (Tangrea et al. 1992; Nesher and Zuckner 1995). Pittsley and Yoder (1983) were the first to describe the bone toxicity of these compounds which induce ossification diathesis; specifically affecting axial skeleton and typically producing bridging hyperostosis resembling DISH (Tangrea et al. 1992, Nesher and Zuckner 1995). This was corroborated by Gerber et al. (1984) whose retinoid-treated patients reported back and neck stiffness and their spinal radiographs showed changes resembling DISH. They also indicated that the symptoms abated when the administration the drug was stopped. Ellis et al.’s (1985) study of seven patients in high dose of isoretinoin for 10-16 months also showed that the patient receiving the highest dose developed small hyperostosis at the thoracic spine and the navicular. In a long-term, randomised and placebo-controlled clinical trials aimed at evaluating the efficiency of low-dose of isoretinoin to prevent basal cell carcinoma showed that, 36 months after the start of the trial, there was an increased number of patients showing vertebral changes consistent with DISH (Tangrea et al. 1992). Other cases have also shown a relationship between the administration of vitamin A derivatives and DISH (Petscavage et al. 2010; Schadt et al. 2011). However, Ling et al. (2001) suggested that the DISH-like hyperostosis only occurs when the drug dosage is high. Their results show that short or long term low-dose prescription of isoretinoin does not cause significant radiological abnormalities. The authors also indicate that long-term high dose only posed increased risk of hyperostoses in old patients, concluding that in any case, the hyperostosis are asymptomatic and thus clinically insignificant (Ling et al. 2001). Similar results had been reported by Kilcoyne et al. (1986) who, in a study of 96 patients treated with low doses of isoretinoin for at least 4 months, found that only 10 patients developed small pointed vertebral excrescences of unknown clinical relevance. Also Carey et al.'s (1988) study of 120 patients treated with a low dose of isoretinoin showed that 12% of the patients presented minimal hyperostosic changes; changes also seen in 8% of the control group. The authors considered that the relationship between isoretinoin and DISH was not clinically significant (Carey et al 1988).

A.1.3.4 Genetic background

Some studies have suggested that DISH could be related to some genetic or immunological factor. For example, Gorman et al. (2005) reported severe cervical changes, without extensive thoracic involvement, consistent with DISH in, at least, three members of the same family. Their tissue typing results suggested that if DISH was genetically linked, it was not related to HLA (Human Leukocyte Antigen) status. The authors concluded that the lack thoracic involvement was an atypical feature of DISH which could mean that this was either a new pathological identity separated from DISH or simply an anomalous case of this same disease (Gorman et al. 2005). A similar study investigated the possible link between the HLA system (particularly the HLA-27 antigen) and DISH in the Pima Indians from Arizona (Spagnola et al. 1978) arguing that both factors (DISH and HLA-B27) are much more prevalent in this community than in Caucasians. However, the prevalence of HLA-B27 in a sample of 44 male adults (over 55 years old) with DISH and in a sample of 33 age-matched control individuals was found to be similar (16% and 20% respectively, p-value=0.9) suggesting no evident association between DISH and the HLA antigen (Spagnola et al. 1978).

Another example of different members of a single family affected by DISH was reported by Bruges-Armas et al. (2006). 103 individuals belonging to 12 unrelated families from The Açores were assessed by rheumatologists and radiologists. 70 patients had ectopic ossifications, joint pain and radiographic enthesopathic changes and 52 were diagnosed with DISH. 12 patients were diagnosed with concomitant DISH and chondrocalcinosi, a rheumatic disorder resulting from the accumulation of calcium pyrophosphate dehydrate in connective tissues associated with metabolic and endocrine imbalances. The pattern of familiar chondrocalcitosi was found to be autosomic-dominant and monogenic thus, according to the authors, the co-occurrence of DISH and this form of chondrocalcinosis suggested a shared pathogenic pathway for both conditions and a possible genetic origin of DISH (Bruges-Armas et al. 2006)

Tanaka et al. (2003) successfully related single nucleotide polymorphisms (SNPs; variant DNA sequence in which the base of a single nucleotide has been replaced by another base) in gene COL6A1 to the ossification of the spinal posterior longitudinal ligament (OPLL). Since both conditions share the hyperostotic factor, it has been suggested that the same gene could possibly be related to the development of DISH (Tsukahara et al. 2005). Tsukahara's et al. (2005) results show that there is a relationship between the COL6A1 gene and the development of DISH in the Japanese population but not for the Czech populations thus arguing that the genetic involvement in the development of the condition could therefore be population-specific. Following the same reasoning that OPLL and DISH could have the same aethiopathology, Havelka et al. (2001) studied COL11A2, identified by Koga et al. (1998) to be related to OPLL (ossification of the posterior longitudinal ligament) in the Japanese population. Havelka's et al. (2001) results showed that, in the Czech population, this relationship is also non-existent.

A.1.4 Complications derived from DISH

For a very long time, DISH has been considered to have no clinical symptoms. In fact, it was even argued that DISH was a status of health instead of a condition (Hutton 1989) or doubted whether the condition had any actual clinical relevance at all (Schlapbach et al. 1989; Beyeler et al. 1992; Tangrea et al. 1992). Hutton (1989) and Schlapbach et al. (1989) suggested that DISH could be a protective reaction since the people with DISH tended to suffer from less back pain and degenerative conditions such as osteoarthritis, osteoporosis and fracture. However the extension of the life expectancy has allowed the progression of DISH to further stages and the development of related complications.

Dysphagia (difficulty in swallowing) is one of the most commonly complications reported in patients with DISH (Utsinger 1985; Hughes et al. 1994; Mata et al. 1997; Epstein 2000; Calisaneller et al. 2005; Ebo et al. 2005; Miyazawa and

Akiyama 2006; Oppenlander et al. 2009; Urrutia and Bono 2009; Vengust et al. 2010). Dysphagia is caused by the pressure of the osteophytes against the relatively immobile portion of the oesophagus at the level of the cricoid cartilage (C3-C4 level) (Mader 2002). Mader (2002) reported that it was present in 10.5% of the DISH patients over 60 years old. A similar percentage of 10% in 40 patients with DISH was reported by el Miedany et al. (2000). Nelson et al. (2006) specified that usually DISH-related dysphagia worsens with solid food and Marks et al. (1998) and Naik et al. (2004) reported that the ossification impedes the intubation and laryngoscopy for exploration and can cause laryngeal oedema.

Other reported complications arisen from the ossification at the cervical spine are: apnea (transient cessation of respiration) and nocturnal dyspnea (difficult respiration during sleep), hoarseness (rough or harsh voice) and stridor (harsh vibrating sound heard during respiration in cases of obstruction of the air passages) secondary to osteophytic growth at C3-C4 and aspiration pneumonia (Hughes et al. 1994; Papakostas et al. 1999; Mader 2002; Matan et al. 2002; Naik et al. 2004; Ebo et al. 2005; Nelson et al. 2006; Vengust et al. 2010). The osteophytic bridges between vertebrae have also been reported to have an impact on the mobility of the spine as they can reduce neck rotation and thoracic movements (Resnick et al. 1978; Eviatar and Harell 1987; Mata et al. 1997; Ebo et al. 2005)

Pain has been reported in the late-stage cases of DISH but the relationship between the progression of DISH and pain is also poorly understood. Utsinger (1985) and Resnick (2002:1476-1503) indicated that DISH patients commonly suffer from back pain and stiffness in the morning. This was confirmed by Mata et al. (1997) and Ebo et al. (2005). 45% of El Miedany's et al. (2000) patients with

DISH reported back pain. Patients with DISH diagnosed before 50 had more pain in the thoracic and lumbar region compared to a control group with OA and also referred significantly higher frequencies of upper limb pain and weakness than control subjects (this difference was statistically significant) (Miyazawa and Akiyama 2006; Mader and Lavi 2009). Belanger and Rowe (2001) also indicated that mild pain could appear at the areas of ossification. However, other studies reported no significant differences in the frequency of back pain in any spinal level between patients with DISH and the control group (Schlapbach et al. 1989). In fact, the results published by Holton et al. (2011) indicated that, in men between 65 and 100 years of age, DISH patients reported less pain than the control group. In two consecutive studies assessing the relationship between DISH and pain, it was found that elbow pain was not dependant on the DISH status of the patient but that the shoulder pain was closely related to DISH (Beyeler et al. 1990; Beyeler et al. 1992).

A recently identified complication causing concern in the medical community is the high percentage of spinal fractures in cases of DISH and their derived complications (Hannallah et al. 2007, Mader et al. 2013). Hendrix et al. (1994) reported that all of their 15 DISH patients had at least one vertebral fracture and Deiderichs (2011) also reported that 25% of men over 65 years old affected by DISH (n=342) had at least one vertebral fracture. These fractures have been found to be caused by either high or low-energy trauma (Hendrix et al. 1994; Mader 2002; Tanishima et al. 2012). Westerveld’s et al. (2009) extensive literature review on spinal fracture in DISH showed that most of the fractures occur at the cervical spinal portion (60%; 34.5% in the thoracic spine and 5.5% in the lumbar region) and that 32.7% of individuals suffered from complications from this fracture. Furthermore, it also revealed that 20% of the DISH patients died 3 months after the traumatic injury; a considerably higher percentage compared to the 0.4% of individuals who died after spinal trauma but had no spinal ankyloses (Westerveld et al. 2009). The myelopathy and reduced chance of survival when such a fracture occurs is what has led some authors to raise awareness that the presence of spinal ankylosis on a radiograph should lead to a high suspicion of unstable fractures, loss of function and increased risk for unfavourable outcome (Mader et al. 2013; Westerveld et al. 2014).

Associated with trauma, myelopathy (disorder of the spinal cord or bone marrow) is another of the complications that are starting to arise in the advanced stages of DISH (Hendrix et al. 1994; Epstein 2000). Westerveld and colleagues (2009), found that 40% of the DISH patients with spinal fracture demonstrated neurologic deficits and the patients demonstrated little or no recovery of the neurologic function even after the spinal fracture has been reduced. In a retrospective study of patients with traumatic spinal fractures, 30% of the admitted patients with DISH suffered from neurologic deficit associated with the trauma, possibly due to the instability of the fracture and its tendency to displace. These patients also showed significantly higher associated rates of mortality and secondary complications than in control patients (Westerveld et al. 2014). Effect on the lower extremities muscle strength and progressive weight, as well as soreness, gait disturbance and loss of sensation due to DISH have also been described (Storch et al. 2008; Guo et al. 2011). Myelopathy seems to contribute to the unfavourable clinical course and it is, most possibly, one of the causes of the high mortality in patients with DISH that have suffered a traumatic event. However, the general profile of the patients (often of advanced age, showing obesity, diabetes, hypertension and/or cardiovascular disease) possibly also contribute to the bad prognosis of these patients (Westerveld et al. 2014).

In sum, diffuse idiopathic skeletal hyperostosis is a condition that still raises many questions regarding its diagnosis, characteristic manifestations, aetiology and associated risks. Of all these unknowns, this thesis will only consider the early diagnosis of the disease as well as the relationship between the spinal and the extras-spinal manifestations of DISH. The next chapter will define the methodology followed to investigate these questions

A.2 METHODS

The methods described here are aimed to identify the early stages of DISH by recognising the features that clearly differentiate this condition from other spondylarthopathies such as discarthrosis and ankylosing spondylitis. The final goal would be to create a diagnostic criteria that would include all the stages of the disease. This section also outlines the nomenclature used to describe the hyperostotic lesions, their location and extension as well as the changes that may be observed in the endplate. The method to record the location and size of the extra-spinal manifestations is also included. Appendix 2 contains a template of the recording form.

Finally, a short description of the reference collection used in this part of the project as well as the statistical tests carried out to analyse the results are also included.

A.2.1 WM Bass Donated Skeletal Collection: collection demographics

The study of the development of DISH from the early stages to the complete ankylosis has been carried out with the WM Bass Donated Collection (also referred as Bass Collection), curated at the Archaeology and Anthropology Department of the University of Tennessee.

The WM Bass Donated Skeletal Collection was established in 1981 by Dr. William Bass when he initiated a body donation program. While the number of donations grew steadily through time, since early 2000s, there has been an exponential increase and, as of 2018, the Forensic Anthropology Centre that manages the collection has over 4,000 individuals who have registered to donate their body. As part of the donation process individuals provide information about age, sex, ancestry, stature, weight, medical histories, residence histories, occupations and parity (Vidoli et al. 2017). This wealth of information available for each individual was the reason why this collection was chosen to carry out the analysis in this project. There are individuals from every state of the United States of America although most individuals come from Tennessee. It is worth noting that the characteristics demographic profile of the collection depends on the donors and thus is influenced by the individual cultural norms and traditions around death and dying (Shirley et al. 2011) nevertheless, individuals from all walks of life are represented in the collection (FAC 2017).

Of the nearly 1800 individuals curated, 65% are males and the remaining 35% are females. The collection contains individuals between 19 and 99 years of age however the majority of the sample is centred between 55 and 70 years of age at the time of death (Figure 3). Finally, with regard to ancestry distribution, 89% of the individuals were white, 5% black, 4% white or other and 2% Hispanic (FAC 2017).

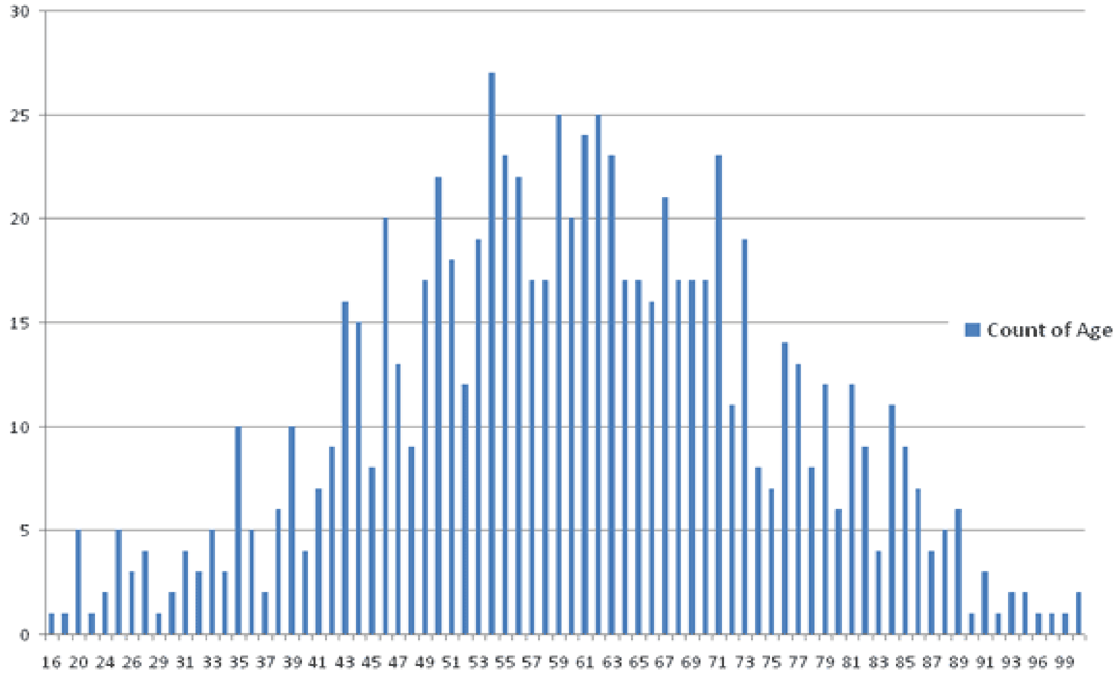


Figure 3: Age distribution of the sample from the WM Bass Donated Skeletal Collection (Source: adapted from FAC 2017)

In comparison, according to the US Census Bureau (2017), the American population is composed by 50.7% females and 49.3% males and regarding the individual ancestry, 79.2% of the population are considered whites, 14.5% black or African American, 6.7% Asian, 2% American Indian or Alaska Native and 0.5% Native Hawaiian or Pacific Islander (US Census Bureau 2017). This data suggests that as a sample, the WM Bass Donated Skeletal Collection does not truly represent the US population since its demography is significantly different than that described by the US census.

Because of the asymptomatic character of DISH, all the individuals were diagnosed post-mortem at the Department of Anthropology at the University of Tennessee using the method described in Ortner (2003: 558-560). Ortner (2003:559) quotes, in turn, Smythe and Littlejohn (1998) for the diagnostic criteria. Smythe and Littlejohn (1998) indicated that the “diagnosis is based on a radiological finding in which new bone forms bridges across the amphiarthrodial (or cartilaginous) joints of *four contiguous vertebral bodies*” adding that there should not be intervertebral disc disease, sacroiliitis and the apophyseal joints from the affected vertebrae should not be affected. As it was extensively discussed in section A.1.2.1, this kind of considerations will introduce a bias *par force* as only the most advanced cases of DISH fulfilled this criteria.

Thus while the demographic results presented in here cannot be extrapolated to the wider modern US population, the sample is still suitable as a source of data to identify and describe the early lesions of diffuse idiopathic skeletal hyperostosis and to investigate differences in lesion expression within the spine in advanced cases.

For the analysis, as a result of how this collections is being assembled, the preservation of the elements is usually excellent and, for the majority of the individuals, all vertebrae were present and recordable. The original number of individuals with DISH was 52.

A.2.2 Description of the recording of the spinal manifestations of DISH

As a starting point clarification, when talking about vertebral bodies, unless specifically stated, all the lesions are located at the anterior surface. To facilitate the specific localisation of the outgrowths, the anterior surface of the vertebral body has been divided into nine sections as indicated in Figure 4.

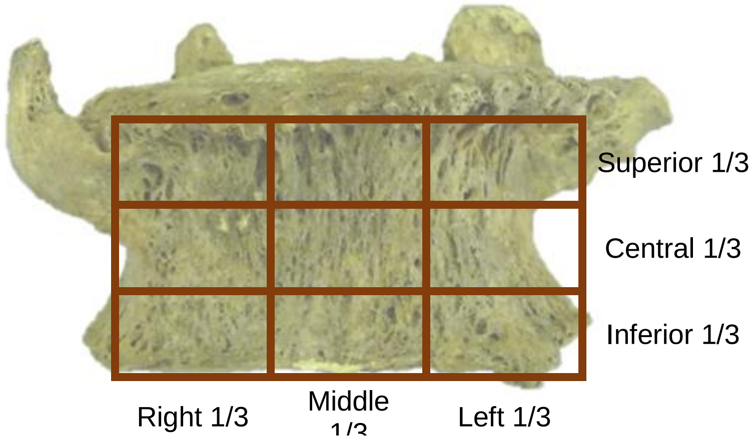
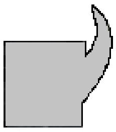
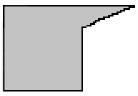
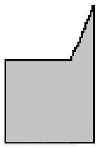


Figure 4: Representation of the quadrants on the vertebral anterior surface used to locate the spinal outgrowths

A.2.2.1 Shape of the vertebral outgrowths

Derived from the previous studies, three types of outgrowth have been identified and assigned to different conditions. Each one can be differentiated from the other two types of outgrowth according to their shape and origin location. Table 3 shows the three types of outgrowths their main characteristics and the condition they have been traditionally associated with.

Table 3: Types and characteristics of the outgrowths found in the spine (source image: author)

Outgrowth type	Origin	Shape/orientation	Condition associated	References
 DISH outgrowth	Central third portion of the vertebral body	Candle-like or flowing ossification	DISH	Forestier and Rotés-Querol (1950), Crubézy (1989)
 Osteophyte	Superior or inferior endplate margin	Horizontal. When developed, can adopt a vertical orientation	Vertebral osteophytes - discarthrosis	Steinbock (1976), François et al. (1995), Maat et al. (1995)
 Syndesmophyte	Superior or inferior endplate margin	Vertical orientation	Ankylosing spondylitis	Chanchairujira et al. (2004)

A.2.2.2 Nomenclature for the DISH-related vertebral outgrowths

All outgrowths were identified and separately classified as:

1. *Isolated outgrowth:* spur of smooth compact bone rooted at the central section of the anterior surface and has not been met by another outgrowth from an adjacent vertebra (see Figures 5 and 6).
2. *Touching or interlocking outgrowths:* the outgrowths of two adjacent vertebrae are correspondent and had become big enough as to touch or interlock but have not formed yet a complete bone bridge (see Figures 5 and 7).
3. *Ankylosed outgrowths:* the outgrowths from two adjacent vertebrae had completed the formation of an intervertebral bridge (see Figures 4 and 8).

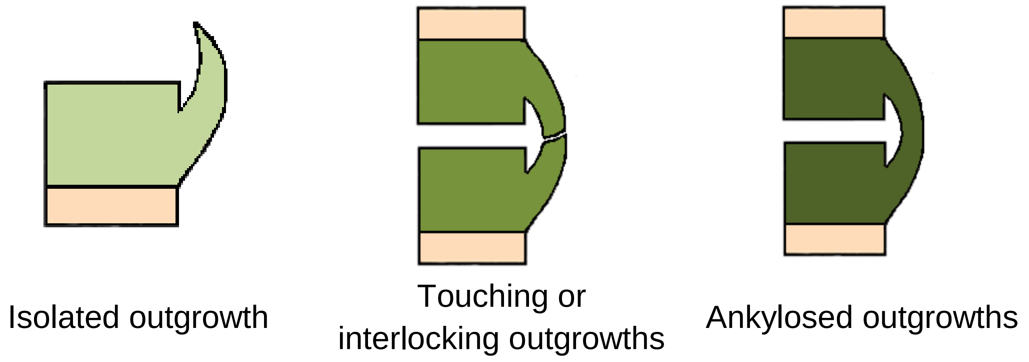


Figure 5: Representation of the progression of the spinal outgrowths associated to DISH (source: author)

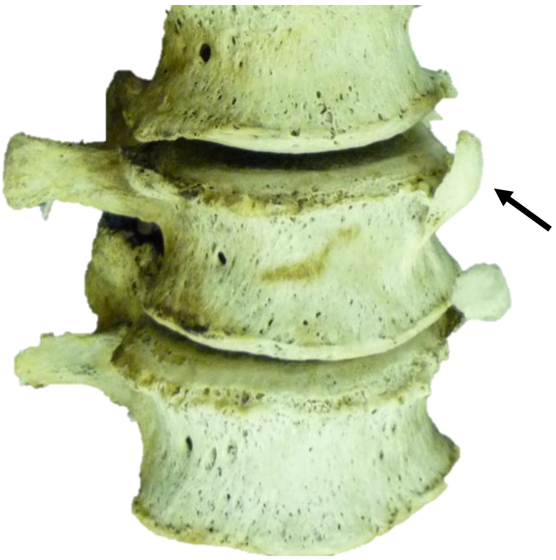


Figure 6: Example of isolated outgrowth in lumbar vertebra (arrow). Individual 7 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 7: Example of touching or interlocking outgrowths in thoracic vertebrae (arrow). Individual 1768 from the Hereford Cathedral collection (University of Bradford) (source: author).

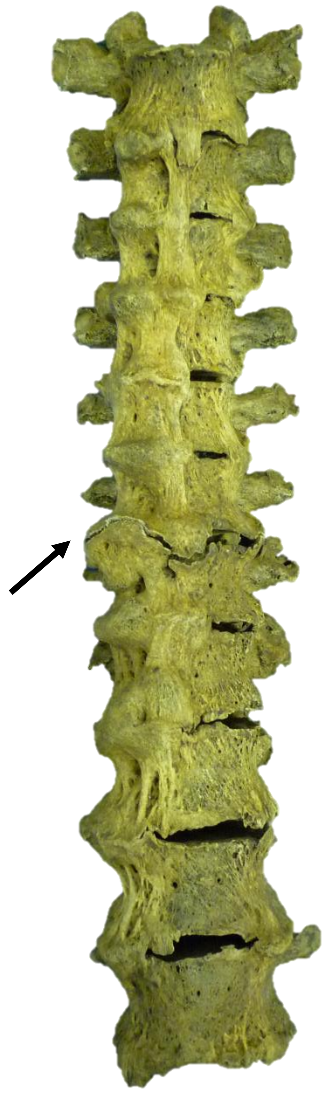


Figure 8: Ankylosed outgrowths forming complete bridges expanding across the thoracic and the lumbar vertebrae. Arrow: interlocking lesion. Individual 12 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

A.2.2.3 Location and degree of intervertebral disc degeneration in DISH.

This projects stems from the results obtained in the MSc dissertation by the same author (Castells-Navarro 2013). During the analysis, it was confirmed that, as previously suggested, a positive diagnosis of DISH was compatible with the presence of degenerative disc disease; possibly due to the fact that both features are age-related (Crubézy 1989; Rogers and Waldron 2001; Villotte et al. 2010; van der Merwe et al. 2012).

In this earlier report, it was noted that the stage of DISH development had an inverse relation to the level of disc degeneration. So, the greater or more exuberant the outgrowth, and the more advanced the disease was, the lesser degree of degeneration could be observed. Furthermore, while degenerative lesions on the endplate can be observed co-existing with DISH, these are, in most cases, unlikely to be found next to the DISH-related outgrowth, being more commonly found in adjacent vertebrae. Finally, in the case when both lesions co-existed at the same endplate, the degenerative lesions were not located at the same area of the DISH outgrowth (Castells Navarro 2013). Thus it is hypothesised that the development of the DISH outgrowths protect the degeneration of the endplate and therefore that there is very little or no spatial relationship between these two features.

To further understand the relationship between vertebral disc degeneration and the characteristics of DISH and confirm these observations, a diagram to locate the degeneration has been designed (Figure 9) and used to record all the observable endplates of the individuals with DISH from the WM Bass Donated Skeletal Collection.

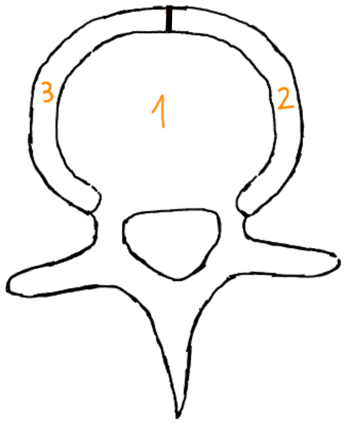


Figure 9: Generic diagram of a vertebra (superior view). The numbers represent different areas of the vertebral plate. 1) central area corresponding with the nucleous pulposus. 2) Right half of the annulus fibrosus. 3) Left half of the annulus fibrosus. (Source: author).

The relation between the location of the disc erosion and the DISH-related outgrowth or the osteophyte was classified as:

- *Non-overlap or unaccompanied*: if the area of erosion did not coincide with the area occupied by the DISH outgrowth (Figures 10 and 11).

- *Less than 50% overlap*: if the area of erosion partially co-located with the area occupied by the DISH outgrowth (Figure 12 left).

- *Complete overlap:* if the area of erosion completely co-located with the area occupied by the DISH outgrowth (Figure 12 right).

The degree of endplate degeneration was also recorded and classified according to the features observed as follows:

- *No degeneration*: the endplate showed no degenerative lesions (Figure 10).

- *Microporosity:* the endplate showed an area with pores lesser than 1mm of diameter (Figure 11).

- *Microporosity with erosion:* the endplate showed microporosity accompanied by cortical erosion (Figure 12 left).

- *Macroporosity:* the endplate that showed an area with pores greater than 1mm of diameter (Figure 12 right).

Figure 10: DISH outgrowth *not accompanied* by degenerative lesions on the endplate. Individual 302 from the site of Blackfriars (University of Bradford) (source: author).

Figure 11: Microporosity at the endplate of a lumbar vertebra. Individual 13 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 12: Left: vertebral endplate showing microporosity with erosion partially overlapping with the DISH outgrowth (arrow). Right: macroporosity completely overlapping with outgrowth. Individual 46 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

A.2.3 Description of the recording of the extra-spinal manifestations of DISH

In 1975, Resnick and colleagues published, for the first time, a systematic study of the enthesopathies related to DISH, also referred as the extra-spinal manifestations. These enthesopathic changes have been included in some diagnostic criteria however there has been a very limited research as to how these develop. Furthermore, recent studies suggests there is little consensus among specialists about their nature and belonging to the same pathologic entity as the spinal manifestations (see section A.1.2).

The entheses that are more commonly cited to be affected by enthesopathies are: olecranon process (*M. triceps brachii* tendon entheses), base of the patella (*M. quadriceps femoris* tendon entheses) and calcaneal tuberosity (*M. triceps sureau* or Achilles tendon entheses). However neither the presence of enthesopathies nor their distribution are exclusive of DISH, for instance it seems that they can also be related to age and activity-related enthesopathies. Nonetheless, according to Crubézy (1989) and Kacki and Villote (2006) DISH-related enthesopathies are usually symmetrical and they measure at least 2mm in height.

Given the lack of consensus as to the relationship between the spinal and the extra-spinal manifestations, in this project, the abovementioned entheses prone to show extra-spinal manifestations that could be related to DISH were observed and any lesions measured and recorded. The enthesopathies were measured vertically from the base to its most distal point using a digital callipers (Figure 13). The size of the measured enthesopathy was rounded up to nearest 0.1 mm.

Figure 13: Example of how the extra-spinal manifestations were measured. Individual 520 from Gambier Parry Lodge (G 9/83 W, University of Bradford) (source: author).

While originally it was not intended to explore the prevalence of entheseal changes at the iliac crest, as during the analysis in the Bass Collection, their presence was noticed on several individuals, their presence or absence was finally recorded. Entheseal changes at the iliac crest can take the form of small spicules or bigger lesions named “whiskering” after the shape of the outgrowths (Figures 14 and 15 respectively).

Figure 14: Superior view of the right os coxa showing small spicules at the iliac crest (arrow). Individual 34 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

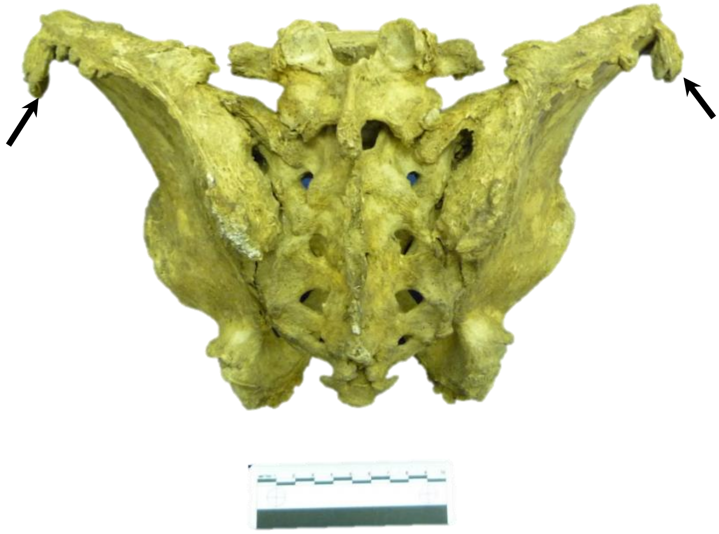


Figure 15: Posterior view of the pelvis showing the bilateral ankylosis of the sacroiliac joint and the hanging outgrowths at the iliac crests (arrows). Individual 14 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

A.2.4 Statistics applied

All the statistical analysis were carried out using the SPSS version 25 software package. To investigate the relationship between age at death of the individual and the total number of vertebrae involved in the ankylosis as well as to evaluate the correlation between the number of vertebrae involved in the ankylosis and the size of the enthesopathies, Spearman's rho Correlation analysis was applied. To reduce the probability of false positives resulting from the high number of statistical operations produced, the significant threshold (p-value) was reduced to 0.01 instead of the widely used 0.05 (Benjamin et al. 2018). Furthermore, to ensure the robusticity of the analysis, the statistical analysis was considered two-tailed.

Both, the age of the individuals as well as the size of the extra-spinal manifestation was included in the tests as indicated in the medical history of each individual and as measured during the analysis, respectively. Finally, quantitative analysis was applied to evaluate the relationship between DISH and the presence of other metabolic, diet or nutrition-related conditions.

A.3 RESULTS

The study of the Bass Collection aimed to confirm that the identification of early DISH was possible and that the outgrowths showed the features documented in the previous work of the same author on archaeological material (Castells-Navarro 2013). The analysis intended to confirm the association between the spinal and the extra-spinal manifestations of the condition as well as the link between DISH and age, sex and ancestry, and the morbidity with other diet-related conditions (e.g. diabetes, obesity and diet-related imbalances).

A.3.1 Description of the population with DISH of the WM Bass Donated Skeletal Collection

A.3.1.1 Characteristics of the sample: age and sex distributions

Initially, the curated remains of 52 individuals (see demographics below) from the WM Bass Donated Skeletal Collection, University of Tennessee (Knoxville, TN) with a positive post-mortem diagnosis of DISH by the resident anthropologists following Ortner's (2003) criteria were analysed. At the point of analysis it was considered that any individual with a record or evidence of *spinal surgery or trauma coinciding with the area of development of DISH* would be excluded from the analysis. This was decided after prior archaeological analysis showed that the spinal ankylosis resulting from a spinal trauma was not always differentiable from DISH ossification. For example, Figure 16 shows the combination of a DISH-like ossification between T3-T4, T5-T11 and T12-L2 and two areas of spinal trauma, one involving T12 and T1 and the other between L2 and L5 identified by the resident anthropologists (Steadman 2015; pers. comm.), the author, and noted at the medical history of the individual. As it can be observed in the Figure

16, the trauma-related ossification is remarkably similar to the DISH ossification observed between T3 and T11 (e.g. smooth, bulging and sparing the apophyseal joints of the affected vertebrae) which makes it very complicated to clearly identify the aetiology of the ossification between L2-5 and, in its turn, to evaluate the true extension of DISH.

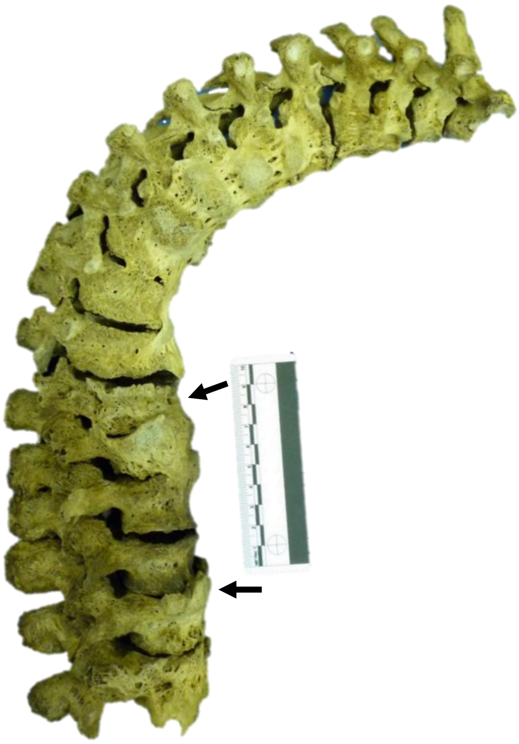


Figure 16: DISH-like ankylosis combined with a medically identified spinal trauma between T12-L1 and L3-L5 (arrows) Individual 49 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

The remains of 44 individuals (31 males and 13 females) between the ages of 51 and 89 were analysed and their biological data is summarised in Tables 4 and 5. The youngest male was 51 and the youngest female, 55. For the ancestry distribution, there was one black individual and the remainder were white. It should be noted that this distribution makes this sample not representative of the US American population (see section A.4.1 for discussion).

Table 4: Biological information of the male individuals analysed

ID	Sex	Age	Ancestry	DISH bridges
1	M	51	W	T3-T11
2	M	52	W	T7-T8
3	M	54	W	T5-T12
4	M	55	W	C4-C5, T3-T4, T5-T12
5	M	56	W	T6-T10
6	M	56	W	T5-T10
7	M	57	W	T7-T10
8	M	61	W	T3-L1, L2-L3
9	M	61	W	T2-T3, T3-T10
10	M	61	W	C2-C4, T6-T11
11	M	63	W	T8-T11
12	M	63	W	C5-C6, T3-L1
13	M	64	W	T4-T10
14	M	65	W	T4-T12
15	M	66	W	T3-L1
17	M	67	W	T6-T7, T8-T10, T11-T12
18	M	68	W	T9-T11
20	M	69	W	T9-T11
21	M	71	B	T3-T4, T9-T11
22	M	71	W	T1-T2, T8-T10
23	M	71	W	T3-L1
24	M	72	W	T10-L1
26	M	73	W	C6-C7, T3-T12
27	M	75	W	T4-L1
30	M	78	W	T8-T10, T12-L1
31	M	79	W	T2-T12
32	M	81	W	T3-T11, T11-L1, L5-S1
33	M	81	W	C6-C7, T2-T12
34	M	81	W	T6-T7, T8-L1
36	M	88	W	T2-T3, T4-T9, L1-L2
37	M	89	W	T4-T12

Sex: F: female; M: male. Ancestry: W: white; B: black. Following the Data Protection Guidelines from the WM Bass Donated Skeletal collections, identification numbers (ID) have been given to all individuals from this sample. From here onwards, the individuals will be referred to by their allocated IDs only.

Table 5: Biological information of the female individuals analysed

ID	Sex	Age	Ancestry	DISH bridges
38	F	55	W	T6-T10
39	F	61	W	T7-T10
40	F	63	W	T4-T11
42	F	67	W	T6-T11
43	F	68	W	T6-T10
44	F	69	W	T9-T10
45	F	75	W	T5-T10
46	F	75	W	T4-T8
47	F	77	W	T2-T11
48	F	80	W	T4-T5C, T7-T9, T10-T11
50	F	82	W	C7-T1, T4-T6, T9-T11
51	F	84	W	T2-T11
52	F	89	W	T7-T12

Sex: F: female; M: male. Ancestry: W: white; B: black

The most common age group in the male and the female subsamples is between 60 and 69 years old. Interestingly, the proportion of male individuals between 50 and 59 years of age is three times higher than that of females while there is twice as many females aged between 80 and 89 compared to males. The proportion of males and females in the categories between 60 and 69 and 70 and 79 is very similar (Figure 17).

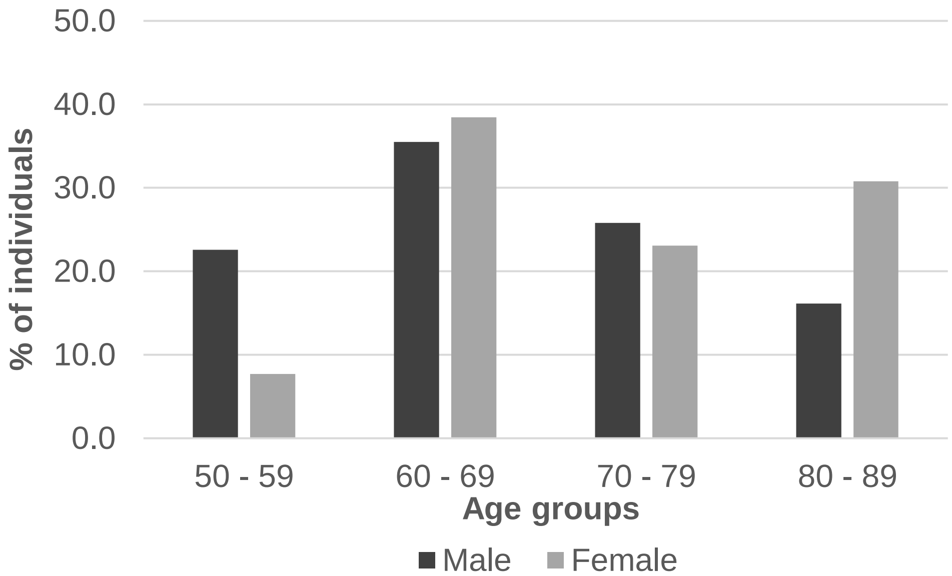


Figure 17: Age distribution of the analysed individuals (n. males= 31; n. females= 13)

A.3.1.2 Relationship between age and number of vertebrae involved in the ankylosis

Diffuse idiopathic skeletal hyperostosis has been recurrently related to an ageing population (Section A.1.1) however, in this sample, the statistical analysis shows a non-statistically significant correlation between the true age of the individuals and the number of vertebrae involved in the ankylosis (r=0.215; p=0.161). If the sample is distributed in age groups by decade, the analysis also shows a non-statistically significant correlation between the two variables at the threshold of 0.01 imposed (r=0.291; p=0.055). Finally, the analysis of correlation in the female subsample shows a non-statistically significant but strong correlation between age of the individuals and the number of vertebrae involved in the ankylosis in both cases, when the true age is considered and when the individuals are distributed in age groups (r=0.536; p=0.059 and r=0.567; p=0.044 respectively). Contrastingly, in both cases, males show a non-statistically significant and weak correlation between these two variables (r=0.216; p=0.242 and r=0.292; p=0.110 respectively).

Table 6 shows the distribution of the number vertebrae (classified in three groups; two to five, six to nine or 10 to 13) affected by the pathology in each age group. Figure 18 shows this same information but represented in percentages of the number of individuals in each age group having two to five, six to nine or 10 to 13 vertebrae involved in the ankylosis. This figure shows that the more advanced the age, the higher the percentage of individuals with a high number of affected vertebrae, suggesting a clear correlation between old age and the development of a very extensive vertebral ankylosis. A similar but less clear correlation between age group and number of affected vertebrae is seen for the individuals with six to nine vertebrae affected. Finally there is a similar number of individuals with two to five vertebrae affected in all age groups except between 80 and 89 years which could suggest that the onset of DISH is variable and/or that the development of DISH is not always continuously progressive.

Table 6: Distribution of the individoduals depending on the number of affected vertebrae and age

Number of vertebrae affected	**Age groups**			
	50 – 59	60 – 69	70 – 79	80 - 89
2-5	4	6	5	0
6-9	3	7	2	5
10-13	1	3	4	4
Total	**8**	**16**	**11**	**9**

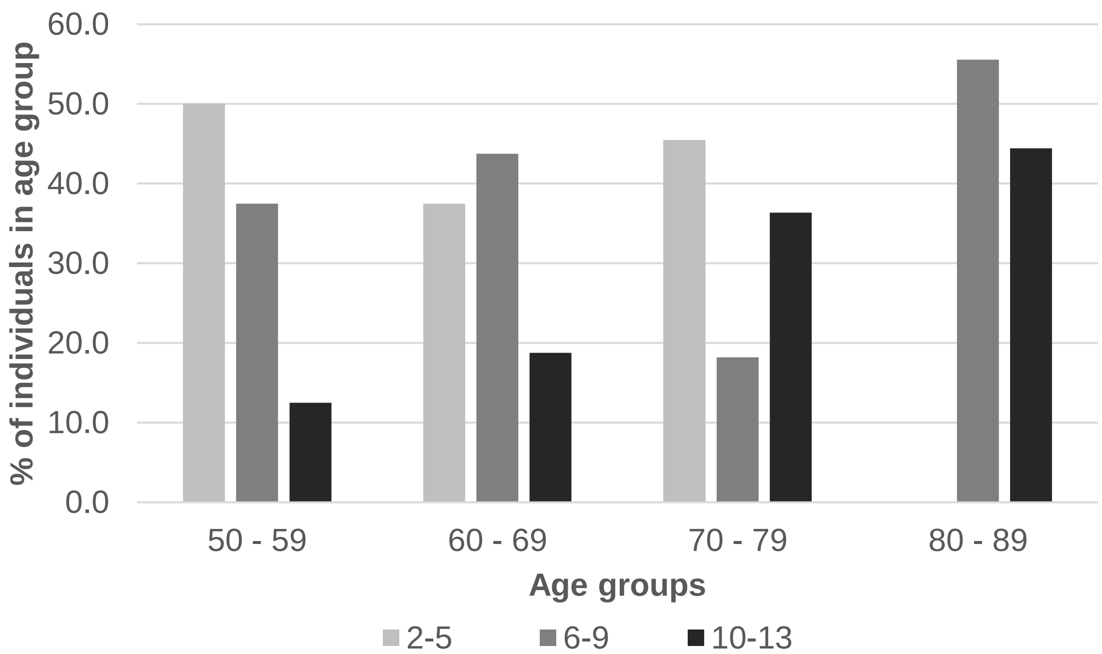


Figure 18: Percentage of individuals with N affected vertebrae per age group

A.3.2 Characterisation of the DISH-related outgrowths and identification of isolated DISH lesions

As the spinal ankylosis is a progressive condition characterised by expanding cranio-caudally, it was hypothesised that the developing early stages preceding the complete ankylosis of the bone bridge between two adjacent vertebrae would be located at either end of the ankylosed block. The analysis of the modern individuals confirmed that at either side of the main block of ankylosed vertebrae, there is usually a variable number of vertebrae with touching outgrowths (Figure 19). And beyond these vertebrae with touching outgrowths, some vertebral bodies show isolated non-touching bone outgrowths (Figure 20).

Figure 19: Touching DISH-related outgrowth between T10 and T11 (arrow) located beyond the main ankylosis. Individual 46 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

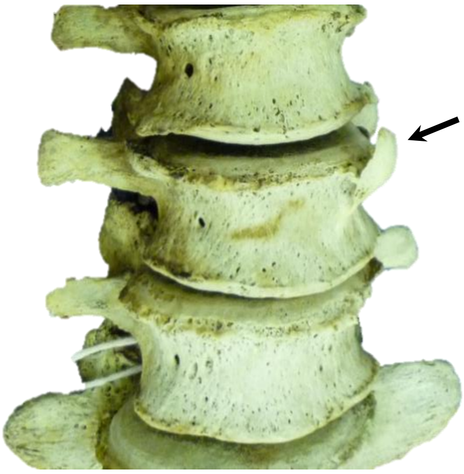


Figure 20: Isolated DISH-related outgrowth (arrow). Individual 7 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

When, as a result of post-mortem damage, the architecture of the DISH outgrowths becomes visible, it is notable that the structure of all the outgrowths, independently of their stage of development, mirror the bone structure of the normal bone: an external well-organised, smooth and compact cortical bone and an internal trabecular bone (Figure 21). The entire appearance of the lesion looks as though this ossification is an extension of the vertebral body itself. As was noted in the methods section, at all stages of development, DISH-related lesions are vertical in orientation, usually rooted at the central third or at the interphase between the central and the upper/lower thirds of the vertebral body. When the lesion reaches the level of the intervertebral disc, it usually bulges outward, becoming thicker than what it is at the level of the vertebral body. This pattern was consistent throughout the Bass Collection sample and it is consistent with the original description offered by Forestier and Rotes-Querol (1950) in their seminal paper (see Section B.4.2 for discussion).

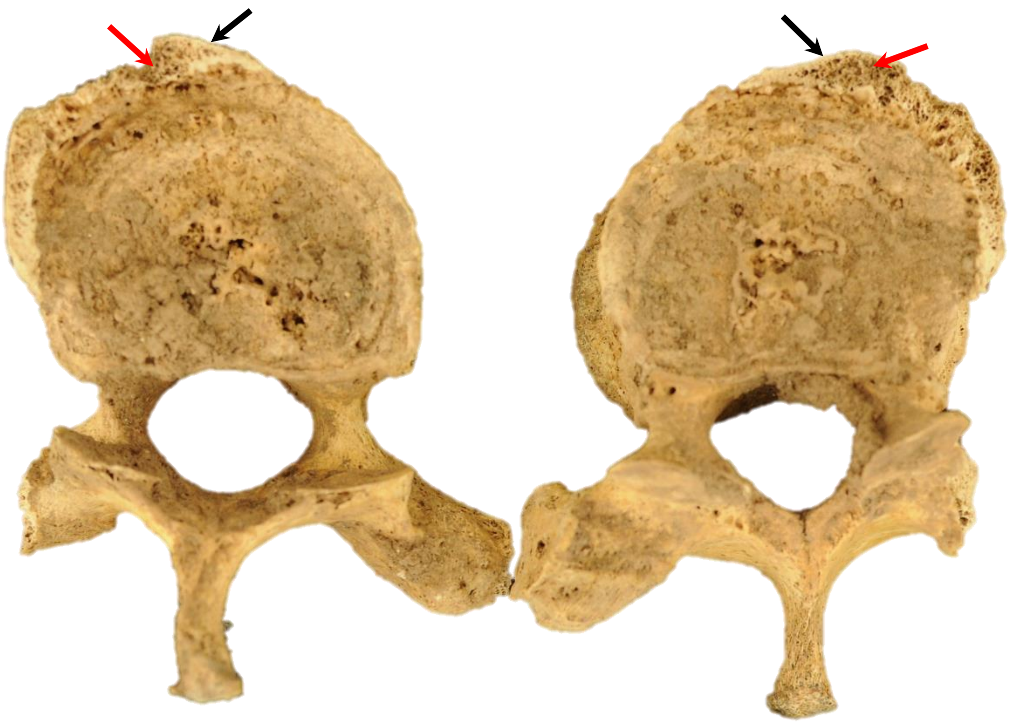


Figure 21: Thoracic vertebra showing a broken spinal DISH outgrowth. Note the structure of the ossifiation as a thin compact outer layer (black arrow) and an internal trabecular organisation (red arrow). Individual 705 from the archaeological site of Hereford Cathedral (University of Bradford) (source: author).

A.3.3 Total number of ankylosed vertebrae and distribution of the ankylosis in DISH

The distribution of the ankylosis was analysed to confirm hypothesis that the lower thoracic vertebrae were the most commonly affected in DISH. The analysis of the 44 individuals showed a remarkably consistent pattern of ankylosis. The lower thoracic vertebrae, and more specifically T10 (41/44, 93.2%), T9 (41/44, 93.2%), T8 (38/44; 86.4%) followed by T7 (35/44; 79.5%) and T11 (29/44; 65.9%) are the vertebrae most commonly involved in the formation of the spinal ankylosis (Figure 22, see Appendix 3.1 and 3.2 for a visual representation of all the spines studied from the Bass Collection).

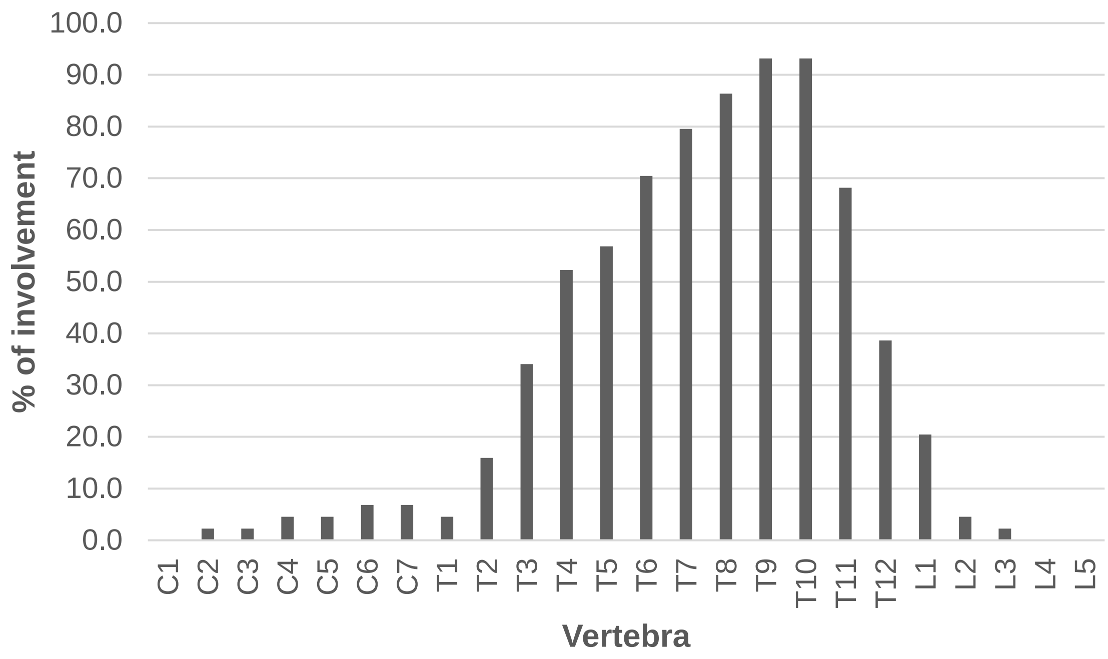


Figure 22: Representation of the distribution of the ankylosis in the Bass Collection sample

The observation of the ankylosis has also revealed that, despite being mainly located at the antero-lateral surface of the vertebral bodies, the ossification shifts its position as follows: the first four thoracic vertebrae the ossification is located on the central third of the vertebral body; from the 5^{th} to the 10^{th} thoracic vertebra, the ossification shifts to the right half of the vertebra. Finally, from T10 to L5, the ossification usually splits in two and shifts to the lateral thirds of the vertebral body (Figure 23).

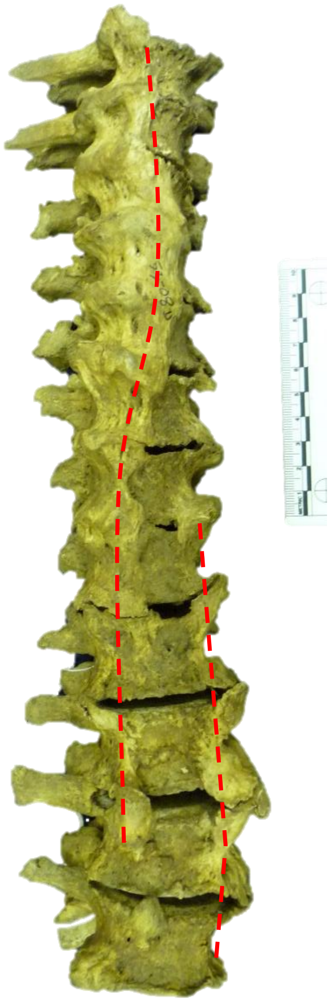


Figure 23: Shift of the DISH ankylosis as marked with the dashed red line (T4-L3). From the antero-central third at the proximal section (T4-5), to the antero-right third (T5-10) and split into two lateral, one right and one left, bands at the last section of the ankylosis (T10-L3). Individual 14 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

In cases of very advanced DISH, intervertebral bridges can also be observed at the left side of the thoracic segment as well as the central third section of the lower thoracic and the lumbar segments. These lesions are typically smaller and less voluminous than the traditional DISH outgrowths and do not tend to form a continuous sheath of more than two vertebrae as it is commonly seen in the contralateral side (Figure 24).

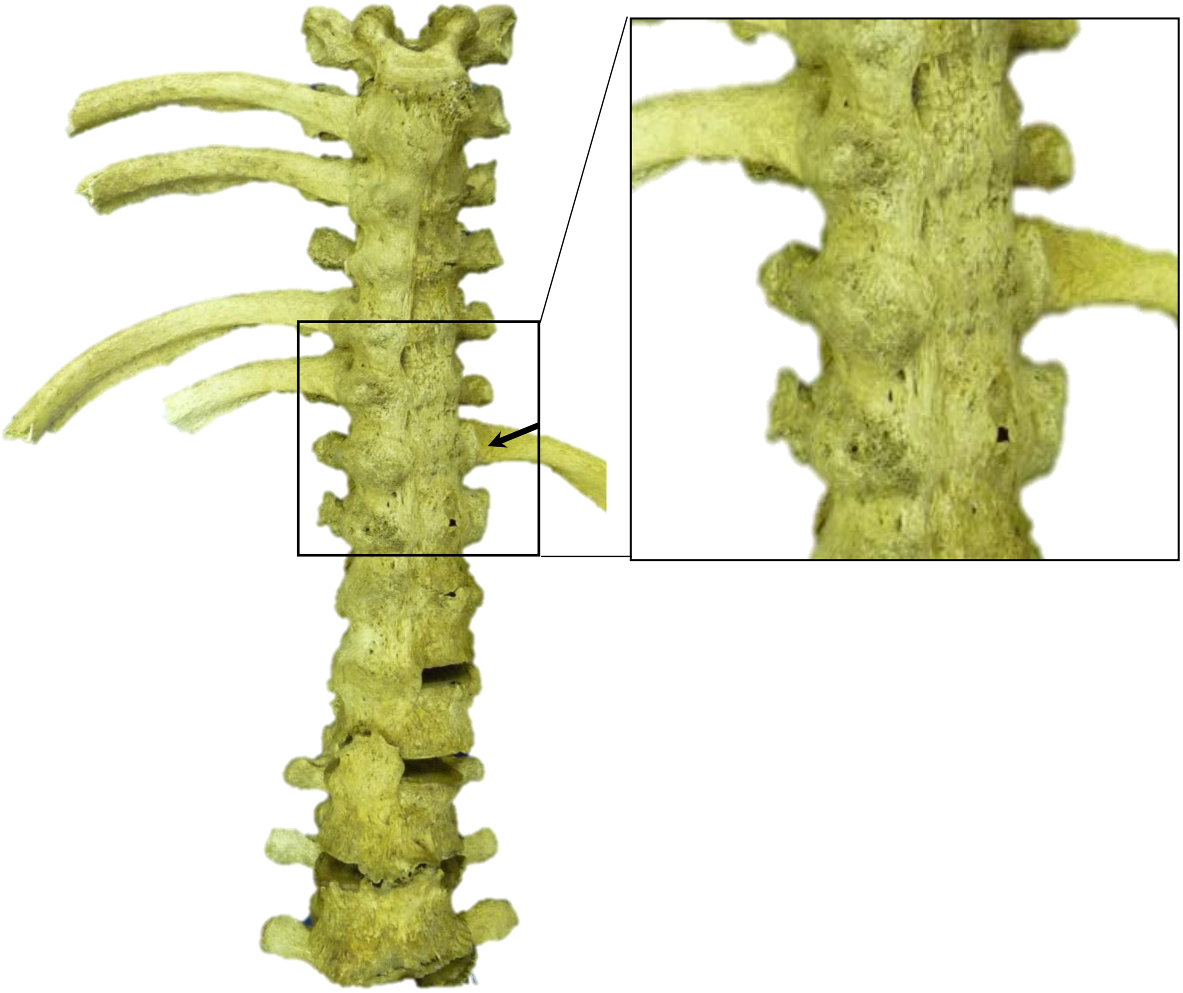


Figure 24: Thoracic section of the spine with DISH showing the voluminous ankylosis at the right side and the flat ankylosis on the left side (black arrow and in the close up). Also note the fusion of the ribs to the vertebrae. Individual 26 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

A.3.4 Status and characteristics of the endplate in DISH. Co-morbidity of DISH with degenerative disc disease and discarthrosis.

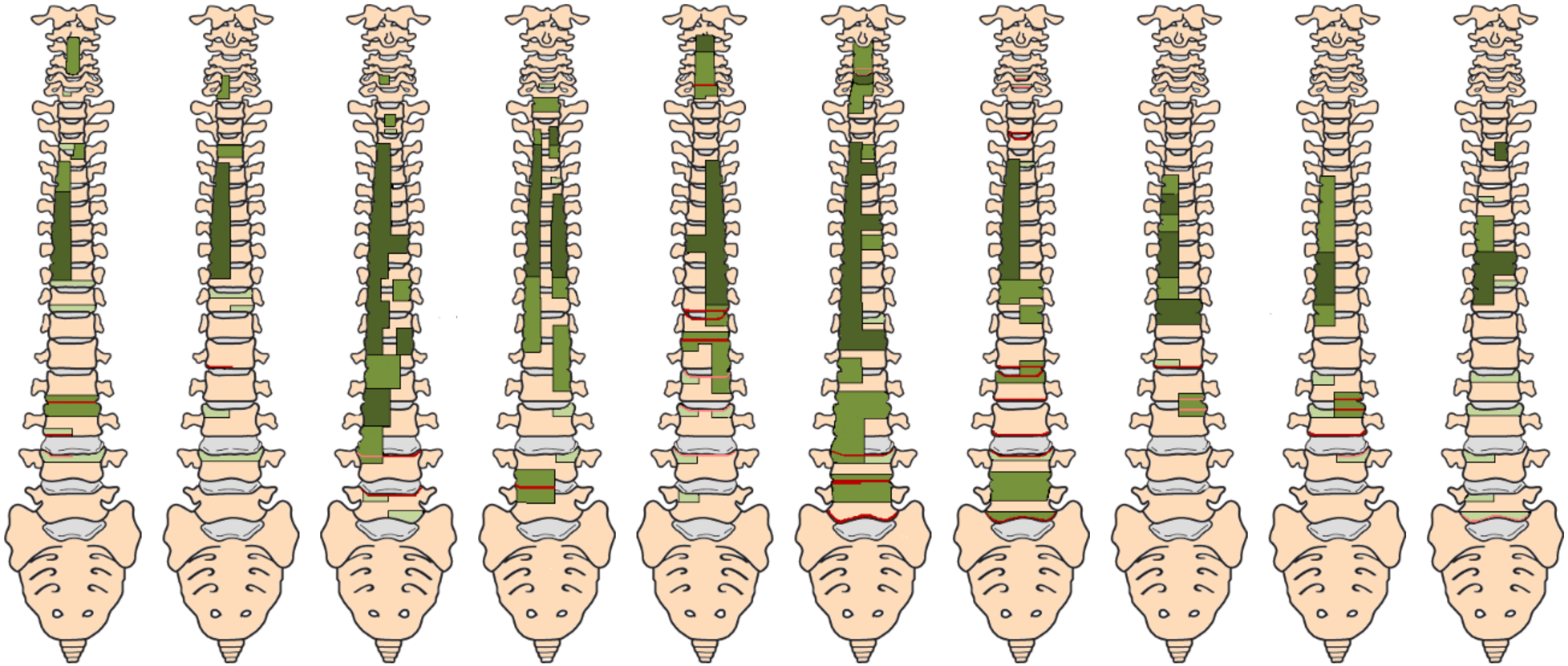
In the clinical literature, there has been some discussion regarding the co-existance of discarthrosis and degenerative disc disease and DISH. While both conditions are age related, and thus their co-existance is possible, it is hypothesised that the prior presence of DISH-bridges would prevent the degeneration of the intervertebral disc and thus an inverse relationship between discarthrosis and DISH is expected. For that aim, the characteristics observed at the endplates in the DISH-affected vertebrae are examined and thus the co-morbidity of DISH and endplate degeneration or degenerative disc disease (DDD) as well as with discarthrosis in the same vertebra (Figure 25) will be examined. Table 7 shows, for each individual, which vertebrae had DISH lesions – at any stage of development –as well as the vertebrae showing DISH lesions accompanied by degenerative disc disease, the vertebrae where there is a combination between DISH and discarthrosis and the vertebrae where only discarthrosis lesions are found. Table 8 looks only at the individuals who had at least one vertebra showing DISH lesions with endplate degeneration, breaking down which is the level of degeneration observed and how the DISH lesion and the area affected by the degeneration are related. Individuals 13 and 52 show a combination of ankylosing spondylitis and DISH; for these individuals, only the vertebrae showing DISH lesions were evaluated.

In this sample of 44 individuals, there are 24 individuals (54.5%) with a DISH lesion accompanied by endplate degeneration in at least one vertebra, 17 individuals (38.6%) with at least one vertebra showing a combination of DISH lesions and discarthrosis (as defined by the presence of spinal osteophytes and endplate degeneration (François et al. 1995) and 17 individuals (38.6%) with at least one vertebra with signs of discarthrosis without signs of DISH.

Figure 25: Co-occurrence of an isolated DISH lesion and osteophytes at the superior endplate of a lumbar vertebra. Individual 34 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 26 shows, in percentage of specific vertebrae affected, the locations were a combination of DISH with DDD and DISH with discarthrosis can be found as well as the distribution of discarthrosis in the spine (there were 62 vertebrae affected by DISH and degenerative disc disease, 25 affected by DISH and discarthrosis and 47 vertebrae affected by discarthrosis alone). As it is clear from this figure, the majority of the vertebrae showing a combination of DISH and degeneration of the endplate and DISH and discarthrosis are located in the lumbar section of the spine beyond the reach of the main completed ankylosis.

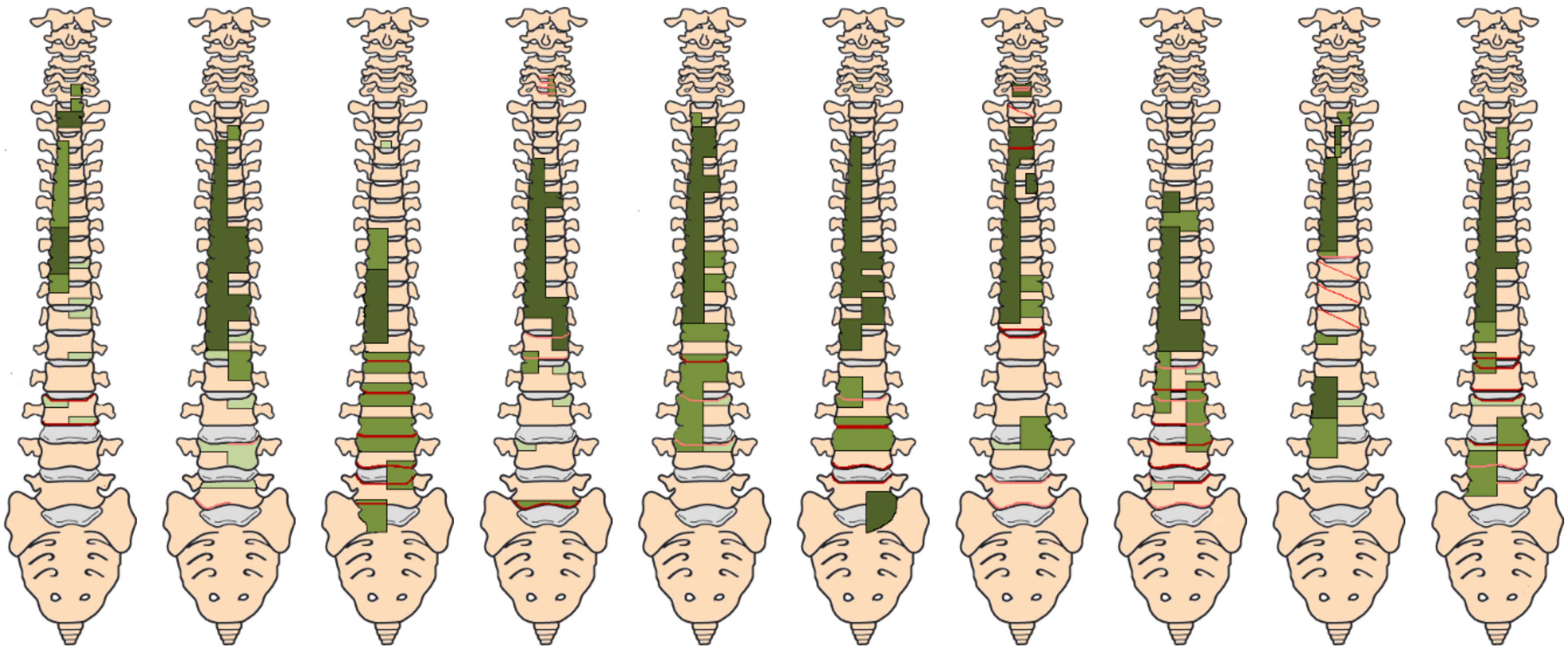
Table 7: Summary drawing of the location of DISH lesions, co-occurring DISH and DDD, discarthrosis and discarthrosis alone in the Bass Collection sample



ID	5	6	8	9	10	12	13	17	18	21
Sex	M	M	M	M	M	M	M	M	M	M
Age	56	56	61	61	61	63	64	67	68	71
Ancestry	W	W	W	W	W	W	W	W	W	B

Colour code: Isolated outgrowths; Touching outgrowths; Ankylosed outgrowths

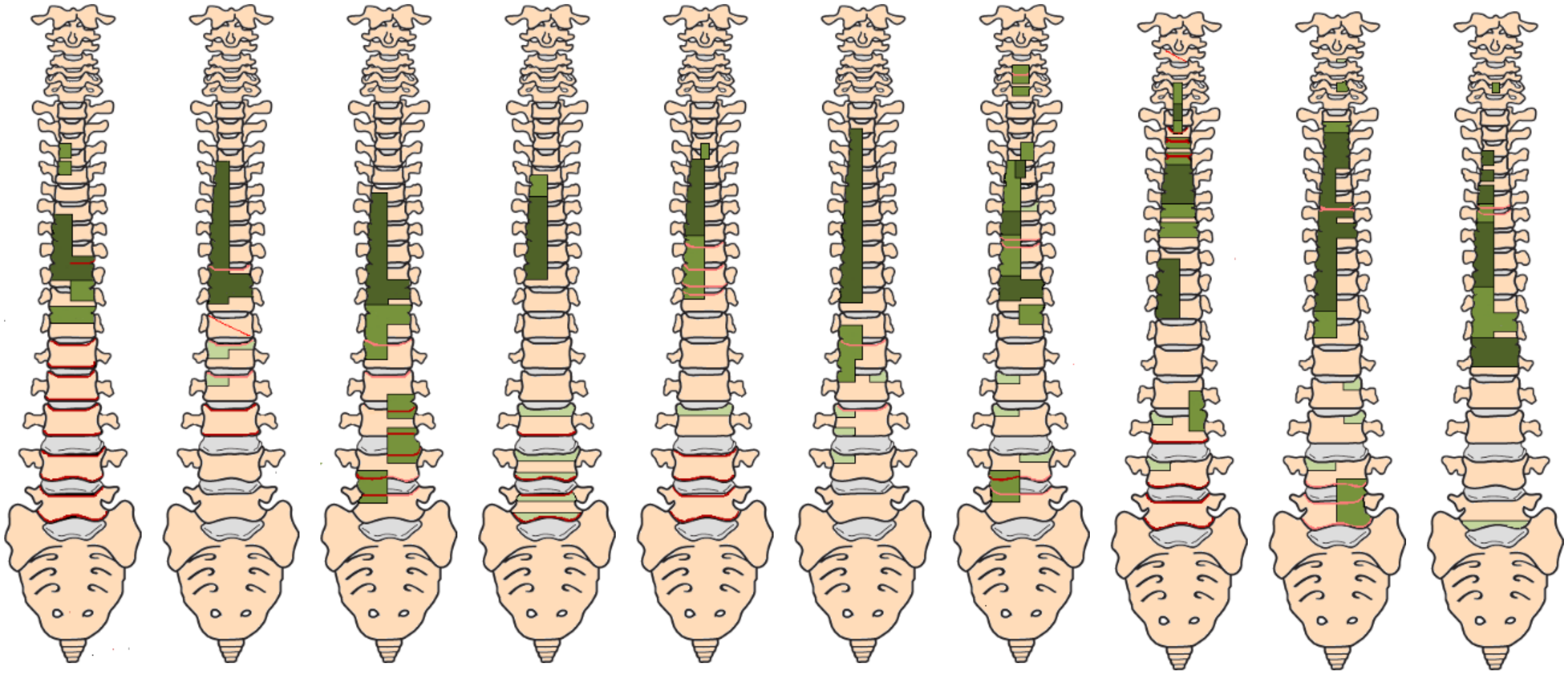
Discarthrosis; Degenerative disc disease



ID	22	23	24	27	31	32	33	34	36	37
Sex	M	M	M	M	M	M	M	M	M	M
Age	71	71	72	75	79	81	81	81	88	89
Ancestry	W	W	W	W	W	W	W	W	W	W

Colour code: Isolated outgrowths; Touching outgrowths; Ankylosed outgrowths

Discarthrosis; Degenerative disc disease



ID	39	40	42	43	46	47	48	50	51	52
Sex	F	F	F	F	F	F	F	F	F	F
Age	61	63	67	68	75	77	80	82	84	89
Ancestry	W	W	W	W	W	W	W	W	W	W

Colour code: Isolated outgrowths; Touching outgrowths; Ankylosed outgrowths

Discarthrosis; Degenerative disc disease

Table 8: Summary of the individuals with co-locating DDD and DISH: degree of endplate degeneration and co-location of the lesions

ID	Sex	Age	Degree of Degeneration			Co-location with DISH lesion		
			Microporosity[1]	Microp + erosion	Macroporosity[2]	No overlaping	50% overlaping	100% overlapping
5	M	56	L4SR	-	-	L2SR	-	-
6	M	56	-	-	-	-	-	-
8	M	61	-	L4SR/L	-	-	-	L4SR/L
10	M	61	L1S, L2S, L4S	T11I, T12S, L3S	C6IL	L4S	T11I, T12S, L1S, L2S, L3S	C6IL
11	M	63	L3S, L4S	L3I	L1I	L4S	L3S/I	L1I
12	M	63	C5, L4S	-	-	-	L4S	C5
13	M	64	-	-	C5I, C6I	-	-	C5I, C6I
14	M	65	-	-	-	-	-	-
17	M	67	L2I, L3S	-	-	-	L2I	L3S
18	M	68	L4SL	-	-	-	-	L4S
21	M	71	-	L5I	-	-	-	L5I
22	M	71	L3I	-	-	-	L3I	-
23	M	71	L4SL, L5IR	-	-	L4SL, L5IR	-	-
24	M	72	T8I	L1I	T9S/I, T10S	-	T8I, T9S/I, T10S, L1I	-
27	M	75	-	C6-7, L1	C5-6, L5I	-	C6-7	C5-6, L1, L5I
31	M	79	L3S, L4S	-	-	-	L3S	L4S
32	M	81	-	-	L3S	-	L3S	-
33	M	81	T6I, T7S, L5I	-	L5S	L5S/I	-	T6I, T7S
34	M	81	L5SR/I	L2S	T7I, T8S, L1I-L4I, L5SL	T8S, L2I, L3I, L5I	L5SR	T7I, L2S, L3S, L4S/I, L5SL
36	M	88	-	-	T9I	-	-	T9I-
37	M	89	-	-	L4I, L5S	-	L4I	L5S

Cont…

Table 8 cont.

40	F	63	T10S, L1S, L2S	-	-	-	L2S	T10S, L1S
42	F	67	-	L1S	L2S, L4I, L5S	-	L1S, L2S	L4I, L5S
46	F	75	T9S, T10S	T10I,	T11S	T9S	T10S, T11S	T10I
47	F	77	L3S	L1S	-	-	L1S, L3S	-
48	F	80	C5I	T9S	T8I, L4I, L5S		T8I, T9S	C5I, L4I, L5S
51	F	84	-	-	T5I, T6S, L4I, L5S/I	T5I, T6S, L4I, L5S/I	-	-
52	F	89	-	T6I	T7S	-	-	T6I, T7S

[1]Vertebral microporosity: presence of pores of smaller than 1mm of diameter at the vertebral endplate. [2]Vertebral macroporosity: presence of pores bigger than 1mm of diameter at the vertebral endplate.

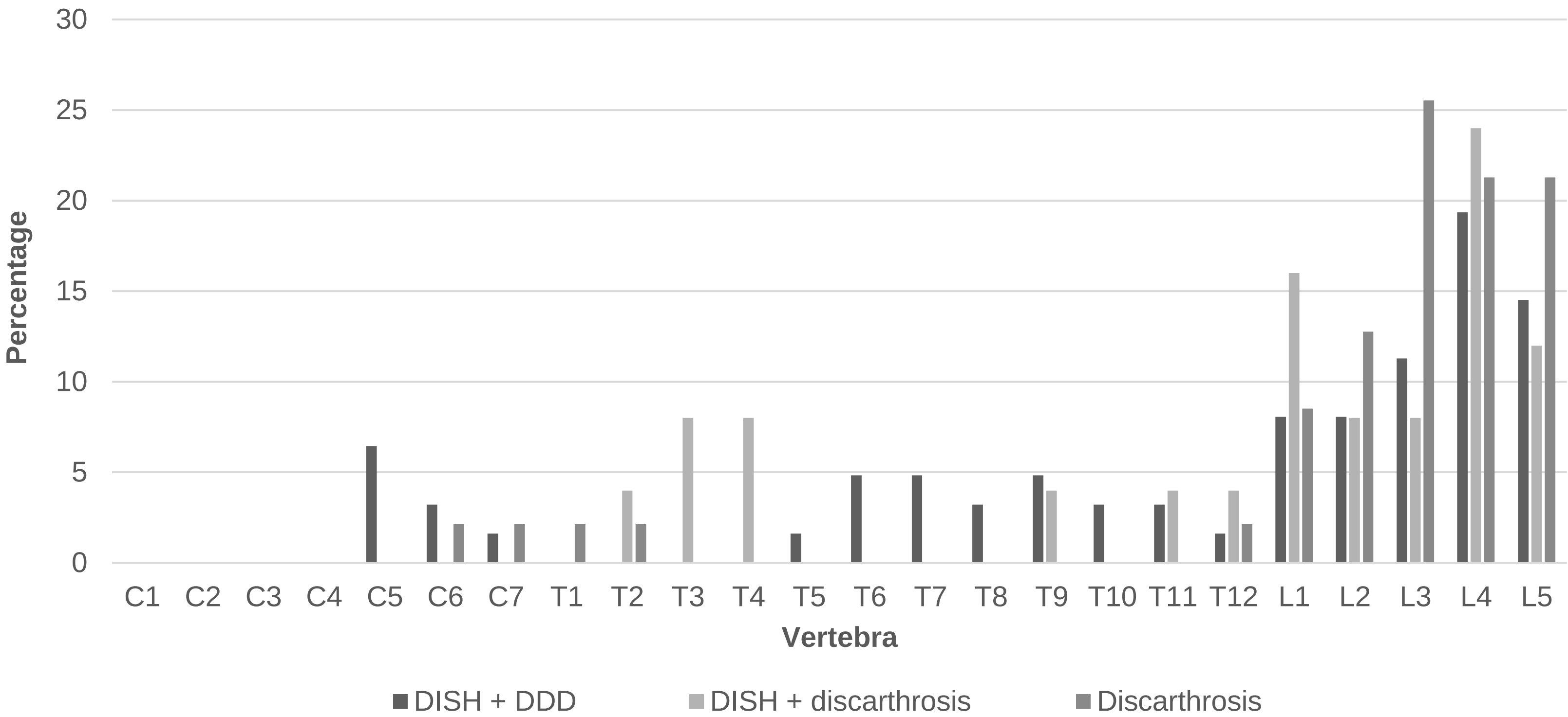


Figure 26: Location of the DISH lesions with degenerative disc disease, with discarthrosis and vertebrae showing only discarthrosis

A.3.5 Description of the extra-spinal manifestations: correlation with age and with the spinal manifestations of DISH.

In this section, the co-morbidity of spinal and extra-spinal manifestations was analysed to investigate if and if so, how, these two manifestations are indeed related. The development of the enthesopathies located at the olecranon, patella and calcaneal tuberosity was examinded as these had been suggested to be the most widely affected in individuals with DISH (Utsinger et al. 1985, Crubézy 1989, Crubézy and Crubézy-Ibáñez 1993). The first observation of the data collected from this modern sample is the remarkable variability in the presence and size of the extra-spinal manifestations. Some individuals show well developed enthesophytes in all the locations, some individuals show no or very small entheseal lesions in any of the locations and some individuals display enthesopathies in some, but not all, the locations. See Appendix 3.3 for a summary table of the extra-spinal manifestations observed in each individual.

A.3.5.1 Presence of extra-spinal manifestations and correlation with age

Extra-spinal manifestations have recurrently been associated to the spinal lesions of DISH however it peripheral enthesopathy are possibly also associated to age (Crubézy 1989; Crubézy and Crubézy-Ibanez 1993; Vidal 2000; Kacki and Villotte 2006) thus it was expected that the size of the enthesophytes would increase with age. The extra-spinal manifestations of the individuals with DISH from the Bass Collection were analysed to examie this association. The results presented here need to be read bearing into account that the significance threshold was set at 0.01 to avoid false positive results. Table 9 shows the correlation analysis between the size of the extra-spinal enthesopathies in right and left ulnae, patellae and calcanei and the age at death of the individuals. The data used for the analysis were the true values of age and of entheseal size. No areas show a statistically significant correlation with age.

Table 9: Two-tailed Spearman's rho correlation analysis between size of the extra-spinal enthesopathy and age at death

		Age at death
Enthesopathy at R ulna	Correlation Coef.	-0.270
	Sig. (1-tailed)	0.088
	N	41
Enthesopathy at L ulna	Correlation Coef.	-0.291
	Sig. (1-tailed)	0.061
	N	42
Enthesopathy at R patella	Correlation Coef.	-0.405
	Sig. (1-tailed)	0.013
	N	37
Enthesopathy at L patella	Correlation Coef.	-0.320
	Sig. (1-tailed)	0.042
	N	37
Enthesopathy at R calcaneus	Correlation Coef.	-0.374
	Sig. (1-tailed)	0.019
	N	39
Enthesopathy at L calcaneus	Correlation Coef.	-0.272
	Sig. (1-tailed)	0.085
	N	41

This lack of correlation between age and the size of the extra-spinal manifestations at the insertion of the *M. quadriceps* femoris and *M. triceps sureau* is also evident in when the data is presented graphically (Figures 27 and 28). The relationship between the ulnar enthesopathy and age has not been represented as most of the individuals do not show any kind of lesion or very small bone spicules. The specific measurements of the enthesopathies observed in each individual analysed can be found in Appendix 3.3. To create these figures, the size of the biggest upward oriented enthesophyte measured in each case has been used.

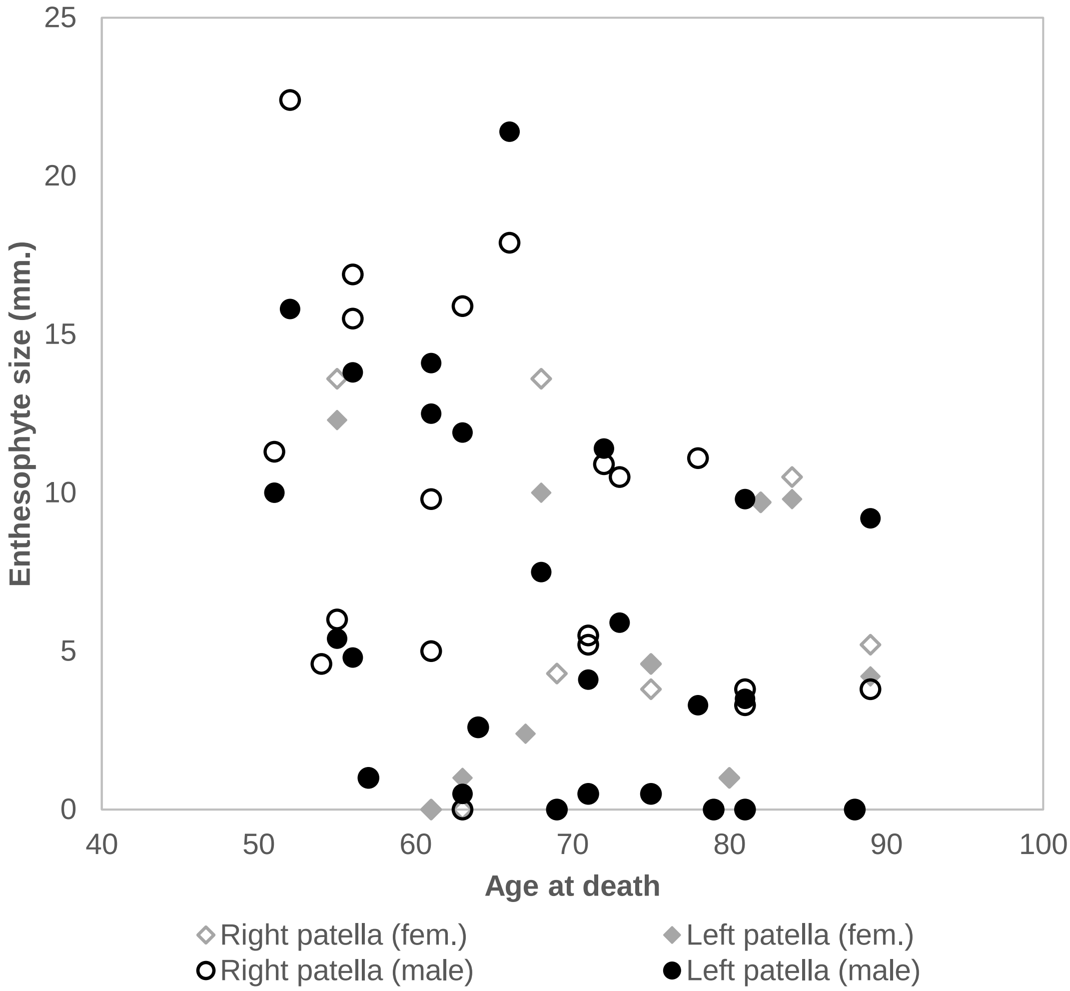


Figure 27: Relationship between size of the enthesophytes at the insertion of the *M. quadriceps femoris* at the calcaneal tuberosity and age at death in the sample from the WM Bass Donated Skeletal Collection

Figures 27 and 28 do not suggest that there is a direct relationship between age and size of the enthesophytes in individuals with DISH. Surprisingly, for both entheses, the biggest measurements are found in the individuals who died before the 8th decade of life. These results then suggest that, at least for this sample, the size of the appendicular enthesopathies is not age-related.

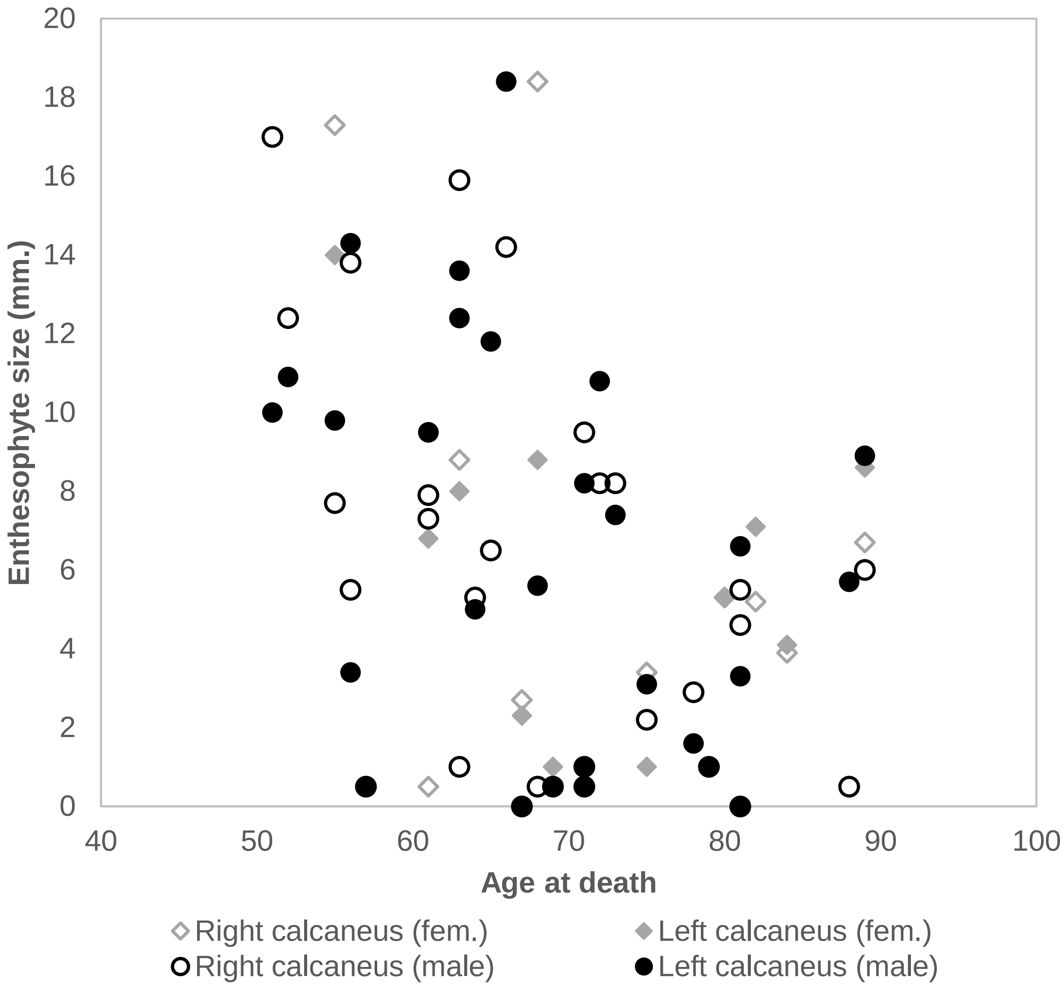


Figure 28: Relationship between size of the enthesophytes at the insertion of the *M. triceps sureau* at the calcaneal tuberosity and age at death in the sample from the WM Bass Donated Skeletal Collection

The extra-spinal manifestations of DISH have been described as bilateral (Resnick et al. 1975) or symmetrical (e.g. Crubézy 1989, Mader et al. 2009). In this sample, 26.8% (11/41) of the individuals showed symmetrical elbow enthesopathies, 60% (21/35) showed symmetrical patellar enthesopathies and 64.1% (25/39) showed symmetrical calcaneal enthesopathies (see Appendix 3.3). Semantically, the concept of “bilateral enthesophytes” suggest that enthesopathies are present at the right and left sides while “symmetrical enthesophytes" suggest that the not only both sides are affected, but that the size of the entheseal changes is comparable (see section A.4.8.1 for discussion). Therefore the results obtained from this sample suggest that while the majority of the individuals show bilateral entheseal changes, DISH-related extra-spinal enthesopathies might or might not be symmetrical.

A.3.5.2 Correlation between extra-spinal manifestations and DISH-related spinal lesions

DISH is described as a progressive condition characterised with spinal and extra-spinal manifestations thus it was expected that the severity of these two features would be related, meaning that the higher number of vertebrae affected by the ankylosis, the bigger the entheseal changes were expected to be. To investigate the relationship between entheseal size and disease progression, Table 10 shows the correlation analysis between the size of the extra-spinal enthesopathies in right and left ulnae, patellae and calcanei and the number of vertebrae involved in the spinal ankylosis. The data used for the analysis was the true number of vertebrae and true size of the biggest entheseal spur. The analysis shows non-statistically significant correlation between the total number of ankylosed vertebrae and the size of the enthesopathy at the ulnae, patellae or calcanei. This suggests that if there is a relationship between these two DISH manifestations, the development and progression of one does not affect that of the other.

Table 10: Two-tailed Spearman's rho correlation analysis between size of the extra-spinal enthesopathy and the total number of ankylosed vertebrae

		Total of ankylosed vertebrae
Enthesopathy at R ulna	Correlation Coef.	0.074
	Sig. (1-tailed)	0.646
	N	41
Enthesopathy at L ulna	Correlation Coef.	0.232
	Sig. (1-tailed)	0.139
	N	42
Enthesopathy at R patella	Correlation Coef.	0.029
	Sig. (1-tailed)	0.864
	N	37
Enthesopathy at L patella	Correlation Coef.	0.176
	Sig. (1-tailed)	0.298
	N	37
Enthesopathy at R calcaneus	Correlation Coef.	0.295
	Sig. (1-tailed)	0.068
	N	39
Enthesopathy at L calcaneus	Correlation Coef.	0.224
	Sig. (1-tailed)	0.160
	N	41

A.3.5.3 Iliac crest enthesopathic lesions

Enthesopathic changes at the iliac crest have been recorded and associated with DISH in the clinical literature (Haller et al. 1989) however to the knowledge of the author, there is no mention of this type of enthesopathic change in the archaeological literature. Out of the 44 individuals, 75% (n=33) show one or the other type iliac crest of lesions. 18.1% (6/33) of the individuals showed spicules, all of which affected both iliac crests. The remaining 81.8% (n=27) show entheseal changes that overhang, at a different levels, from the iliac crest. 92.6% (25/27) of these individuals showed bilateral lesions. There are two additional individuals that show whiskering lesions at the right iliac crest and bone spicules at the left.

A.3.6 Other lesions observed in individuals with DISH

The analysis of this sample showed three other types of lesions possibly associated to DISH: sacroiliac joint (SIJ) ankylosis and fusion of the ribs to the vertebrae, both as a result of the ossification of the respective periarticular ligaments, and the ossification of the costal cartilage effectively fusing the ribs to the sternum. Table 11 summarises the individuals showing these kind of lesions as well as their exact location. Out of the 44 individuals analysed, 27.3% (n=12) showed unilateral or bilateral SIJ ankylosis. The left sacroiliac joint was affected in four out of the five cases where the ankylosis was unilateral. Finally, in one additional case, the left joint appears completely ankylosed while the right ligaments are starting to ossify. It is worth noting that in all cases, the SIJ ankylosis is achieved thanks to the ossification of the periarticular ligaments and in all cases, the intra-articular joint space is retained (Figures 29 and 30).

6.8% (n=3) of the individuals show ankylosis of the costal head to the vertebral costal facets (Table 11). Like the ankylosis observed in the sacroiliac joint, the ligaments surrounding the costovertebral synovial joint are the structures ossifying while the join cavity itself remains intact. It is worth also noting that right ribs seem more prone to ankylose than the left ribs (Table 11). Finally 11.4% (n=5) of the individuals showed ossification of the costal cartilage which ultimately led to the fusion of the ribs to the manubrium and sternum. In all cases, the cartilage of the first rib was affected and only in one case, other ribs were affected (Figures 31 and 32).

Table 11: Summary of the individuals showing sacroiliac joint ankylosis, and rib fusion to the vertebrae or the sternum

ID	SIJ ankylosis	Rib fusion to vertebrae	Costal cartilage ossif.
40	-	-	R/L1
27	R (starting)	R/L*	-
1	L (ankylosed), R (starting)	-	-
8	R/L	-	R/L1, R2, R3, R4, R5 and R6
31	L	R3, R7 and R12	-
12	L	-	-
23	R/L	-	-
14	R/L	-	R/L1
4	-	-	R/L1
30	R/L	-	-
3	R/L	-	R/L1
26	L	R3, R4, R6, R7 and L9	-
10	R/L	-	-
44	L	-	-

SIJ ankylosis: sacro-iliac joint ankylosis. - : feature absent. R: right side affected, L: left side affected, R/L: right and left. *not clear which ribs are fused because there is also intercostal fusion and some ribs have stood in place because adjacent ribs are fused to the vertebrae

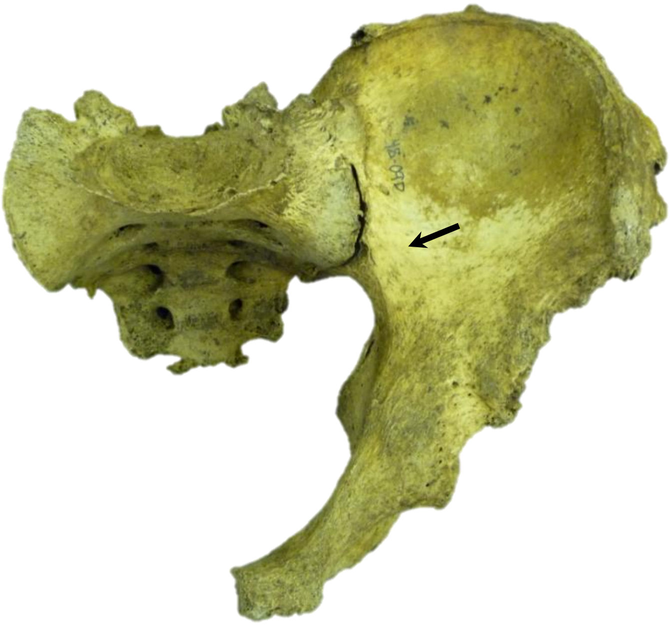


Figure 29: Unilateral sacroiliac joint fusion. Note that the sacroiliac space is preserved (arrow) and the fusion is achieved through the ossification of the periarticular ligaments. Individual 12 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 30: Bilateral sacroiliac joint fusion. Note that the sacroiliac space is still preserved (white arrow) and the fusion is achieved through the ossification of the periarticular ligaments (black arrow) Individual 30 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 31: Ossification of the costal cartilage between the first ribs and the manubrium. Individual 14 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 32: Ossification of the costal cartilage of the right 3rd, 4th, 5th and 6th ribs to the body of the sternum Individual 8 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

This is not the first time that the ossification of the periarticular ligaments of the sacroiliac joint and of the costal cartilage in individuals with DISH has been noted and in fact, it has been considered that DISH is an “ossifying diathesis” affecting tendons and ligaments and while predominantly affects the axial skeleton, extra-spinal lesions are also common (Resnick et al. 1975; Brigode et al. 1982). Furthermore, it has been suggested that individuals prone to extensive enthesophytes (including individuals with DISH) also tend to develop osteophytes, these individuals were named ‘bone formers’ (Rogers et al. 1997) (see discussion A.4.6). It is worth noting that not all the individuals with DISH also show extensive peripheral enthesopathy and osteopathy, possibly suggesting that the predisposition to excessive bone formation (independently of DISH status) does not have the same aetiology as DISH.

Finally, to the knowledge of the author, there has been no systematic study on the calcification of the costal cartilage; in fact, the ossification of softs tissues other than tendon and ligament is not mentioned in the literature. Thus the findings herein reported were not expected. It is possible that this finding is age- and not DISH-related as costal cartilage ossification has even been used in bioarchaeology as an age estimation method (e.g. Işcan et al. 1984; Işcan and Loth 1985). Nonetheless, Mader et al. (2009) noted that the co-morbidity of chondrocalcinosis (deposition of calcium pyrophosphate dihydrate (CPPD) crystal in the joints), ectopic entheseal calcifications and nephrolithiasis (kidney stones) in cases of familial DISH could suggest that other soft tissues not belonging to the musculoskeletal system (e.g. cartilage and arterial walls) could also be affected by the triggering factors associated to DISH. Further analysis on age-known populations will have to be carried out to elucidate the relationship between DISH and costal cartilage ossification.

A.3.7 Summary of the findings about the characteristics of DISH

The data obtained from the individuals with DISH from the WM Bass Donated Skeletal Collection can be summarised in with the following points:

- No correlation was found between age at death and extension of the vertebral ankylosis when all the sample was considered even when males and females are analysed separatedly (see section A.4.2.2 for discussion).
- Early lesions of DISH are vertically oriented isolated outgrowths rooted at the anterior surface of the vertebral body. When observable, DISH-related outgrowths, at all stages of development, show a well-organised and compact cortical external layer encasing the internal trabecular bone structure (see section A.4.3 for discussion).
- T10 and T9 followed by T8, T7 and T11 are the vertebrae most commonly involved in the forming of the ankylosis (see section A.4.4 for discussion).
- The overall shape of the ankylosis seems to follow the aortic shifting from central (between T1 and T4), to antero-right half (between T5 and T10) and finally splitting into two ossified bands located at the right and left lateral thirds of the vertebral bodies between T10 and L5 Intervertebral ossification can also be observed at the left half of the thoracic spine although these lesions are less voluminous and do not tend to form a continuous sheath (see section A.4.4 for discussion).
- DISH and discarthrosis can co-exist in the same spine and even vertebra however their relationship is can appear inverted. This means that the more

advanced DISH is, the less developed discarthrosis is (see section A.4.5 for discussion).

- The study of the extra-spinal manifestations of DISH suggested that there is no correlation between their size and age and there is a remarkable inter-personal variability in the presence of extra-spinal enthesopathies in individuals with DISH (see section A.4.6 for discussion).
- The relationship between the spinal and the extra-spinal manifestations of DISH in the insertion of the *M. triceps brachii* at the olecranon, of the *M. quadriceps femoris* at the base of the patella and the Achilles tendon at the calcaneal tuberosity also showed no statistically significant correlation in the individuals with DISH from the WM Bass Donated Skeletal Collection (see section A.4.6 for discussion).
- Finally, some individuals with DISH can also show excessive bone formation throughout the skeleton as shown by the presence enthesophytes at the iliac crests and the ossification of the sacroiliac periarticular ligaments and costal cartilages (see section A.4.8.3).

A.3.8 The relationship between DISH and other diet-related or metabolic imbalances

As previously noted, one of the great advantages from the WM Bass Donated skeletal collection is that most individuals have their (usually quite detailed) medical history. Using this information, this project evaluated the co-morbidity of DISH with conditions that have been recurrently been linked to DISH however it is worth noting that it was not possible to compare this data with the rest of the Bass Collection sample. It was expected that these individuals with DISH would show a high prevalence of metabolic or diet-related conditions; it is however worth noting that not all the medical histories are equally detailed (Spearman, D. pers. comm.). Table 12 shows the number of individuals suffering from Type 1 or Type 2 diabetes mellitus, morbid obesity, diet-related imbalances (e.g. high blood pressure or hypertension and high cholesterol) and the number of individuals suffering some kind of cardiopathy (e.g. irregular heartbeat, atherosclerotic cardiovascular disease) (see appendix 2.4 for a summary of all the pathologies observed in the individuals analysed). As Table 12 and Figure 33 show, the number and the percentage of individuals not suffering from any type of diabetes is double the number of individuals suffering from this condition. Likewise, out of the 40 individuals, only 5% (n=2) were reported to be morbidly obese and 25% (n=10) seemed to have suffered of other diet-related conditions. While this is surprising given the body of knowledge previously reported (see Chapter A.1.3), it is interesting to observe that there is slightly higher number of individuals suffering of diabetes *or* obesity *or* any diet-related imbalance reported as individuals not suffering from *any* of them (referred as "any metabolic imbalance" in Table 12 and Figure 33). As there was five individuals without medical history, the sample size used in Figure 33 is of 39.

Table 12: Number of individuals suffering of diabetes, obesity or other diet-related imbalances in the studied sample

	Diabetes	Obesity	Diet-rel. imbalances	Any metabolic imbalance	Cardiopathy
Yes	13	2	10	21	15
No	26	37	29	18	24
Not recorded	5	5	5	5	5

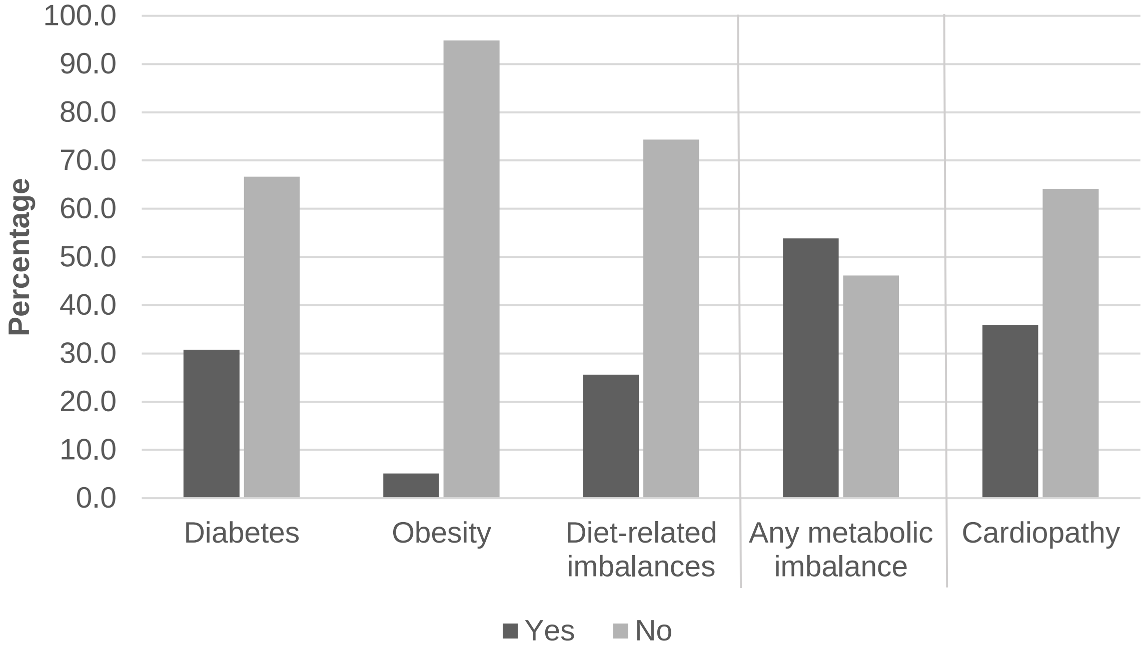


Figure 33: Prevalence of diabetes, obesity and diet-related imbalances in the studied sample (%)

A.4 DISCUSSION

In this section, the results obtained are discussed and commented in relation with previous research. This section will aim at characterising the early stages of development and the progression of DISH, and shed light on the relationship between the spinal and the extra-spinal manifestations of DISH, the link between the spinal ankylosis of DISH and discarthrosis and the co-morbidity between DISH and other diet-related conditions.

A.4.1. Characteristics of the sample: age and sex distributions and correlation with DISH development.

A.4.1.1 Characteristics of the sample: age and sex distributions and related caveats

The original sample of 52 individuals with a post-mortem DISH diagnosis was reduced to 44 after the individuals with spinal trauma or surgery at the same area of the pathologic ankylosis were removed from the sample. In the final sample, there were 31 male and 13 female individuals. Although this seems to reflect the pre-supposed idea that DISH is more prevalent in males (Julkunen et al. 1971; Smythe and Littlejohn 1998), these values could also be a reflection of the much higher presence of males in the original sample. In fact, the male/female distribution of the individuals curated at the WM Bass Collection is 65% male and 35% female (extrapolated to the total number of individuals, there are 1170 males and 630 females in this collection) (FAC 2017). Therefore the prevalence of DISH in the Bass Collection is 2.65% for males and 2.06% for females, suggesting that, in this collection, males do not show a significantly higher prevalence of DISH than females.

In regards to the age distribution of the sample, it was expected, as observed in previous studies (Table 1 in Section A.1.1), that there would be more individuals at later stages of life. However in the sample here evaluated, the majority of the individuals were between the ages of 60 and 70. In the case of males, there was a decrease in numbers at later decades while, comparatively, there was a significantly higher number of women between the ages of 80 and 90. Similarly to what was observed previously, it is very possible that this age distribution mimics the Bass Collection sample distribution which, as abovementioned, contains a higher prevalence of individuals between the mid-fifth and the seventh decade of life. Nevertheless it is worth considering how low the prevalence of females between the fifth and the sixth decade is compared to that of males and, conversely, how this prevalence increases in the later decades of life. Is there a delay in the onset of the disease in female individuals? Is that a reflection of the female longevity? Could it be a combination of both factors? At this moment, with such a small sample and without taking into account the earlier stages of the condition, these questions cannot be successfully answered.

A.4.1.2. Relationship between age and number of vertebrae affected in the ankylosis

As DISH is described as progressive, a direct correlation between age and number of vertebrae involved in the ankylosis was expected, however the results failed to demonstrate this correlation. These results are not altered even when the individuals are distributed by decade. While this was not the result originally expected it is likely that these results are related to inter-individual variability and possibly also linked to the limited sample size (n=44). The results are maintained even when males and females are analysed separatedly. However, as previously indicated, these results need to be taken with caution because of the type of age distribution observed in this subsample as well as in the WM Bass Collection sample are not representative of the wider population and only the more advanced cases have been taken into account.

Nevertheless, it is interesting to notice that the percentage of cases of severe and extremely severe DISH (between six and nine and between 10 and 13 vertebrae involved in the ankylosis, respectivebly) increases steadily with age (Table 6 and Figure 18 in Section A.3.1.2). Finally, the percentage of individuals showing between two and five vertebrae involved in the ankylosis is remarkably stable between 50 and 80 years of age and all the individuals between the ages of 80 and 90 show six or more vertebrae involved in the ankylosis.

A.4.2 Characterisation of the DISH-related outgrowths

The results regarding the advance of the condition seem to suggest that, as expected, beyond the bridging ankylosis, earlier stages of development – represented by touching or interlocking and isolated lesions – can be observed. In all cases, the height of the intervertebral disc space as well as the apophyseal and the sacroiliac joint spaces were respected. Before discussing these findings, it is worth noting that these different lesions (touching or interlocking and the isolated outgrowths), have been classified as the different stages of the same condition because they share the same internal and external structure characteristics. DISH lesions have an external layer of well-developed compact cortical bone encasing an internal structure of organised trabecular bone. This internal structure of trabecular bone seems to be an extension from the trabecular bone infilling the vertebral bodies. The characteristics of the internal and external structure of the DISH-related lesions had, in fact, already been observed and described by Forestier and Rotés-Querol (1950). In their work, the authors noted that “*these hyperostoses have a bony structure with a dense cortex similar to that of the head of the femur, the cancellous bone being in continuity with that of the vertebral bodies”* (Forestier and Rotés-Querol 1950: 328). Furthermore, in all stages of development, DISH-related lesions have a vertical orientation. These outgrowths emerge from the anterior surface of the vertebral body, usually at the central third, and overtake the intervertebral disc at whose level the ossification seems to become thicker (Crubézy 1989; Kacki and Villotte 2006). On dry bone, the combination of these factors (orientation, structure and origin) should allow the differentiation between the DISH-outgrowths and the marginal osteophytes associated to discarthrosis

This is not the first time that the early stages of development of DISH have been noted (e.g. Crubézy 1989; Beyeler et al. 1990; Kacki and Villotte 2006) however, to the best of the knowledge of the author, it is the first time that, on dry bone, they have been systematically recorded and analysed. Crubézy (1989: 110), for example, mentioned the herein described ‘isolated lesions’ by saying that “s*ometimes, in isolated vertebrae or in two non-contiguous vertebrae, this flowing ossifications rooted off to the sides of the spinal plateaus can be seen”.* The author concluded that it would be preferable to classify these observations under the heading *“probable early hyperostosis”* and to not consider these lesions in the calculation of the prevalence of DISH to avoid skewing the population statistics (Crubézy 1989: 110). Resnick et al. (1978: 156) also mentioned that, occasionally, patients between the ages of 20 and 40, show radiographic features that are strongly suggestive of DISH in the form of lower thoracic vertebral excrescences extending between two or three vertebrae, cervical spine body masses and olecranon and calcaneal spurs. But the authors also justified the choosing of four vertebrae as a threshold for the diagnosis of DISH to distinguish it from spondylosis deformans, conceding that lowering the threshold to two or three vertebrae would have increased the incidence of DISH (Resnick et al. 1978: 155).

The identification of the three stages of development makes it feasible to visualise how the formation of the complete bridge might have happened. The analysis of these pre-ankylosing lesions suggest that the complete bony bridge usually described as the “flowing ossification” of DISH can be formed by two distinct processes. One process being the unification of two isolated lesions from adjacent vertebrae growing down- and up-wards respectively, interlocking and finally fusing at the level of the intervertebral disc. Alternatively, some bridges seem to be formed by one isolated lesion growing beyond the intervertebral disc and reaching the adjacent vertebra. In the later cases, the cortex of the vertebra that has not developed the corresponding outgrowth appears more reactive and rugged at the area that will become part of the bridge (Figure 34).

A retrospective anatomical morphological and radiographic study of the changes observable at the insertion of the spinal longitudinal ligaments carried out by Fornasier et al. (1983) allowed the definition of three stages of development in the lesions associated to DISH. In the earliest stage, the authors described flattened spurs arising from the waist of the vertebral body at the entheseal insertion. These spurs progressed to become linear bone depositions running adjacent to the vertebral body. The authors also noted that these spurs where not restricted to the location of the anterior longitudinal ligament but rose from the periphery of the vertebral body (Fornasier et al. 1983:946). In the second stage, the ossification of the ligament formed a continuous band extending across the intervertebral disc space and joined the adjacent vertebral body. The presence of the annulus fibrosus protruding was considered the cause of the "bumpy" profile characteristic of DISH. The final stage was reached when the new bone from adjacent vertebrae confluenced to form a solid bone bridge. The authors noted that interruptions in the ossification at the level of the intervertebral disc space were common (Fornasier et al. 1983).

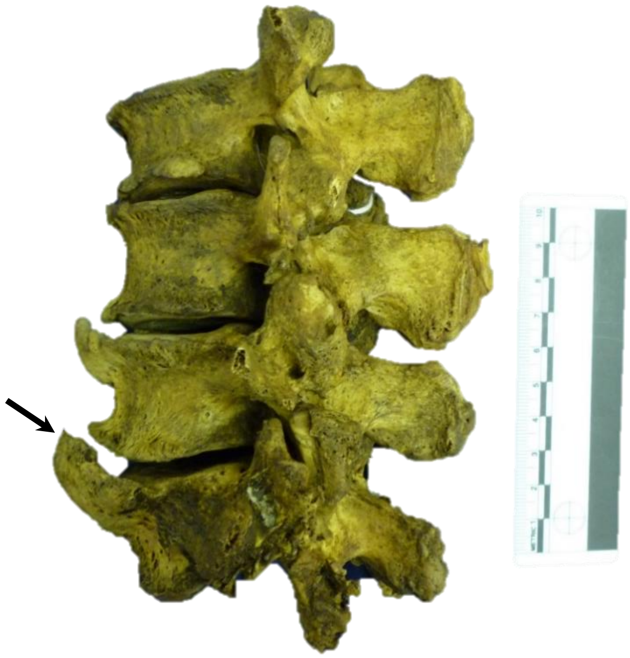


Figure 34: Up-wards growing lumbar isolated DISH lesion overpassing the intervertebral disc and reaching the inferior third of the superior vertebra (arrow). Individual 17 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Trying to understand this process of ankylosis, Resnick et al. (1978: 168-171) suggested that, at least in the thoracic spine, two types of simultaneously occurring, pathologic "aberrations" could be observed. Type 1 was a ribbon-like calcification adjacent to the anterior surface and usually at the central section of the vertebral body although they observed this kind of ossification could also appear at the level of the intervertebral disc. In either case, the ossification, contained within the fibres of the anterior longitudinal ligament, became enlarged, thickened and contained trabecular bone. In Type 2, the aberrant changes were related to the anterior extension of the annulus fibrosis in and around the fibres of the anterior longitudinal ligament which also stretched over the protruding disc. To reach these conclusions, the authors had looked at 25 cadaveric spines that fulfilled their criteria for DISH and thus they could observe the soft tissue.

Sadly, with the human remains here studied, and the methods utilised it was not possible to corroborate finding reported by Fornasier et al. (1983) or Resnick et al. (1978). However the processes explaining the development of the bone bridges described by the present author are compatible with these observations. To confirm these observations and further understand the process of ossification, radiographic and histologic analysis should be carried out in dry bone. These study would also help to understand the relationship between DISH and discarthrosis and their respective entheseal and osteophytic changes.

A.4.3 Total number of ankylosed vertebrae and distribution of the ankylosis

In the analysed individuals from the WM Bass collection, the vertebrae between 7^{th} and the 11^{th} thoracic vertebrae were the most affected by the complete ankylosis (Figure 23 in Section A.3.3). This finding is in agreement with other authors (Harris et al. 1974; Tsukamoto et al. 1977; Resnick et al. 1978). Forestier and Lagier (1971) and Utsinger (1976) also commented that DISH affected mainly the thoracolumbar spine, with the ossification extending to 10 thoracic vertebrae but noting that it could also involve two or three of the cervical and some of the lumbar vertebrae. This development of the ossification beyond the lower thoracic spinal segment was also observed in many of the individuals studied in this project and could suggest either a slow and lengthy or a more rapid and short process of development. It is worth noting that despite this very consistent distribution, there is still no explanation as to why DISH has this tendency to affect this area (Mader et al. 2017) although it has been suggested that the cervical and lumbar mobility might affect the formation of bridges (Forestier and Lagier 1971).

Another feature of DISH receiving wide consensus from the medical and the anthropological scientific communities is that the ossification affects primarily the right half of the spinal column (e.g. Forestier and Rotes-Querol 1950; Forestier and Lagier 1971; Utsinger et al. 1976; Resnick et al. 1978). Traditionally it has been considered that the vertebral distribution of the DISH-related ankyloses was closely related to the position of the pulsating aorta (Forestier and Rotes-Querol 1950). In fact, the shifting distribution – central third of the vertebral body between T1-4; right half of the vertebra between T5-10 and posterior push to the lateral thirds of the vertebral body between T10-L5 (Figure 23 in Section A.3.3) – follows the movement of the descending aorta thus confirming that the formation of the ossification is influenced by this artery. Previous work also found that, at the lumbar region, where the aorta descends anteriorly (Standring and Tunstall 2015: 1087), the ossification was bilateral, although the bone proliferation was not inhibited at the anterior surface (Tsukamoto et al. 1977: 916). This type of distribution was also observed in the sample analysed in this project.

While the text-book DISH ankylosis is typically on the right side, the left side can also show hyperostotic changes, albeit with much reduced volume. These less-developed ossifications on the left side have also been previously observed (Harris et al. 1974, Resnick et al. 1978). Anatomically, the anterior (vertebral) longitudinal ligament is the connective tissue connecting the basio-occipital region to the anterior surface sacral promontory. Surprisingly enough, very little research has been carried out on this ligament in terms on its exact anatomy, however it seems the ligament is formed by fibres of various lengths and primarily located at the central third of the anterior surface of the spine. The three different lengths are: the deep short intervertebral fibres, the intermediate fibres spanning two or three vertebrae and the most superficial ones spanning three or four vertebrae. The anatomical location of the ligament thus does not fully correspond with the lateralised distribution of the main ossification of DISH nor with the possibility of developing contralateral lesions that envelop the entire intervertebral space. This suggests that DISH outgrowths might not be the result of the ossification of the anterior longitudinal vertical ligament itself. In fact, in their original paper, Forestier and Rotés-Querol (1950:326) noted that "*the anterior vertebral common ligament is clearly visible. It is drawn to the left by the outgrowth and the spurs described above are located beneath it*" further indicating that the "*ligament may easily be detached from the spurs though it is firmly attached at the level of the vertebral bodies as well as at the level of the disks [sic]*". In their study of fresh specimens, Forestier and Lagier (1971: 70) observed that the *"anterior longitudinal ligament was partially integrated in the ossification at the level of the intervertebral edges and the pre-disc spaces (although remaining free in front of the actual vertebral bodies)".* The authors suggested that DISH was not the ossification *of* the anterior longitudinal ligament but rather that of a region including this ligament as well as paravertebral connective tissue; invading the peripheral layer of the disc although not the disc itself.

A.4.4 DISH combined with degenerative disc disease and discarthrosis

It was originally hypothesised that the association between age and discarthrosis and DISH would result in the possible co-existence of the two spinal conditions however it was also considered that the prior presence of DISH-bridges would prevent the degeneration of the intervertebral disc. Thus a complex but ultimately inverse relationship between discarthrosis and DISH expected. The results from this study confirm that the relationship between degenerative disc disease (DDD) or discarthrosis and DISH is not straight forward. This unclear relationship is not new, and is demonstrated by the fact that some diagnostic criteria allow for the co-existence of the two features (Crubézy and Crubézy-Ibáñez 1993, Utsinger 1985) while others prevent a positive diagnosis of DISH in the presence of discarthrosis or DDD (Resnick and Niwayama 1976, Arlet and Mazières 1985, Rogers and Waldron 1995, Kacki and Villotte 2006). Theoretically, the co-existence of DISH and discarthrosis or DDD is possible – and to certain point should be expected – since the prevalence of the two conditions increase with age (Prescher 1998; Fujiwara et al. 1999; Listi and Manhein 2012). However the question that remains is whether these conditions could co-exist in the same vertebrae and if so, what are the factors that might influence and sequence this co-morbidity.

Maat et al. (1995: 296) postulated that the increase in the prevalence of DISH in elder individuals was done at expense of vertebral osteophytosis and of vertebral osteoarthritis of the apophyseal joints. They suggested that with increasing age and, in the presence of DISH, the annulus fibrosus' periosteal attachment, the deep fibres of anterior longitudinal ligament and the joint capsule would eventually become ossified. This new all-reaching outgrowth would then mask the previously present osteophytes – located at the transitional area between the annulus fibrosus and the deep fibres of the anterior longitudinal ligament (which attaches to the periosteum, perichondrium and periphery of the annulus fibrosus) – making them anatomically invisible in dry bone (Maat et al. 1995: 296-297). While this hypothesis would certainly explain the seemingly inverse relationship between these two entities, it is worth noting that vertebral osteophytosis – described by Maat et al. (1995: 290) as presence of Schmorl's nodes found in conjunction with non-kissing, kissing or ankylosing bony outgrowths (osteophytes) along the intervertebral margins of a vertebral body – is also known as spondylosis deformans, and this condition always starts with the degeneration of the intervertebral disc (François et al. 1995; Prescher 1998). While not aiming to dwell on the minefield that is the nomenclature used to refer of the structural changes observed in the spine as a result of the degeneration of the intervertebral disc, it is necessary to mention that the degeneration of the intervertebral disc is related to the loss of water content and vertebral structural changes (decreased height, discolouration, fissuring and crumbling of the intervertebral disc). These changes result in the intervertebral disc bulging forwards and the intervertebral space narrowed, osteologically this is identified by the presence of pitting on the superior and/or inferior vertebral endplates in combination with marginal traction (horizontal) osteophytes (Waldron 2009: 43). More recently, this combination of changes has been referred as discarthrosis (François et al. 1995).

Like the data reported by Maat et al. (1995), the results obtained in this project seem to indicate an inverse relationship between these entities: the more advanced the development of DISH, the lower the probability that the same vertebra will show signs of discarthrosis or DDD. However, in view of the state of the endplate in advanced DISH (usually unaffected by endplate degeneration) and its characteristic retention of the intervertebral disc space, it seems unlikely that DISH lesions would hide pre-existent osteophytes, as Maat et al. (1995) suggested, since their “masked” presence should be revealed by the intervertebral disc degeneration and the reduction of the intervertebral disc space. In fact, while it is possible that these results are biased (because many endplates are locked in the bridging ossification and cannot be observed), in the cases where, due to fragmentation, the endplate was observable, generally, these surfaces did not show degeneration. Furthermore, these observations are in agreement with the previous research which suggests that DISH lesions are unaccompanied by disc degeneration or show little endplate erosions (see Table 7 in Section A.3.4) (Crubézy 1989; Lagier 1989; Castells Navarro 2013).

It is nevertheless possible that in the few cases where DISH *is* accompanied by co-locating intervertebral disc degeneration, Maat’s et al. (1995) hypothesis holds true; meaning that the initiation of the disc degeneration process and the formation of the osteophytes preceded the arrival of the DISH lesion and that this bigger lesion masked the pre-existing pathology. This hypothesis would then explain why there is a higher prevalence of co-morbidity between DISH and degenerative disc disease and DISH and discarthrosis in the lumbar segment of the spine. While DISH, discarthrosis and DDD can co-exist in the same spine (and, in some cases, even in the same vertebra), this co-morbidity is much more common at the lumbar vertebrae, where discarthrosis and DDD tend to be more prevalent, than at the cervical or lumbar vertebrae and where DISH tends to develop later.

In view of these results, it is possible to suggest that the co-morbidity between DISH, discarthrosis and degenerative disc disease can indeed occur, but that the development of a vertebral bridges (completed or not) in DISH acts as a protection against the age-related degeneration of the endplate.

A.4.5 Description of the extra-spinal manifestations of DISH

The results obtained in this project suggest a remarkable variation in the presence of the extra-spinal manifestations in DISH individuals. It was considered that if the spinal and the extra-spinal features are part of one same entity, their development would be correlated. However, the results suggest that there is no correlation between the size of the enthesopathies and the number of vertebrae involved in the spinal manifestation (see Table 10 in Section A.3.5.2) nor between the age at death of the individuals and the size of the appendicular enthesopathies (Table 9 in Section 3.5.1).

However in this sample, 64.1% of the individuals (25 out of 39) showed symmetrical calcaneal enthesopathies, 60% (21 out of 35) showed symmetrical patellar lesions and 26.8% (11 out of 41) showed symmetrical olecranon lesions. Furthermore, while not being the main extra-spinal manifestation targeted in this project, this analysis also revealed a high prevalence of pelvic lesions (75%, 33 out of 44), including iliac crest spicules or whiskering and sacro-iliac joint paraarticular ankylosis – in the DISH specimens of the Bass Collection. Finally 27.3% of the individuals showed uni- or bilateral sacroiliac joint ankylosis (ossification of the sacroiliac ligaments). It is possible that these results are the reflection of a significant inter-individual variability.

Harris et al. (1974) based their description of the extra-spinal manifestations of DISH on a sample of 34 patients, 17 men (age range: 47 – 82) and 17 women (age range: 47 – 83) fulfilling the radiographic criteria for definite and severe DISH. Although there is no mention of whether the lesions were symmetrical or bilateral, the group reported that bone changes in the pelvis were the most common and were typically located at the anterior border of the pelvis just above the acetabulae, at the inferior surface of the ischiopubic ramus and at the greater trochanter. Similar lesions were also found at the femoral and tibial condyles and at the fibular heads (Harris et al. 1974: 212) (Table 13).

Table 13: Presence of extra-spinal manifestation reported by Harris et al. (1974), Resnick et al. (1975) and Utsinger et al. (1976)

	Harris et al. (1974)	Resnick et al. (1975)		Utsinger et al. (1976)
N.	37	21 (DISH)	21 (control)	30
Shoulder-humerus	-	8 (38.2%)	-	-[d]
Elbow	-	12 (57.1%)[a]	2 (9.5%)	4 (13.3%)
Wrist-hand	-	8 (38.2%)	-	-
Pelvis	18 (60%)	21 (100%)	5 (23.8%)	-[d]
Fem/tib condyles	2 (5.9%)	3 (14.3%)	-	-
Patella	-	3 (14.3%)	1 (4.8%)	-[d]
Fibula	1 (2.9%)	6 (28.6%)[b]	-	-
Calcaneus	-	16 (76.2%)	4 (19.1%)	8 (26.7%)
Feet	-	15 (71.4%)[c]	-	-

[a]52.3% (n=11) bilaterally affected. [b]19% (n=4) bilaterally affected. [c]57.1% (n=12) bilaterally affected. [d]extra-spinal manifestations referred but no specific prevalence rates were reported.

Resnick et al. (1975) studied the extra-spinal manifestations of DISH in 21 patients (Series A: all male; age range: 49-80) from the Radiology Departments, Veterans Administration and University hospitals, San Diego, pathologic material from 10 autopsied individuals with spinal or extraspinal manifestations of DISH and a control sample of 21 age-matched male patients. From series A, 38.1% (eight of the 21) of the individuals with DISH reported peripheral musculoskeletal complaints. The radiologic study revealed that all individuals showed symmetrical, broad and well-defined pelvic abnormalities (in the iliac crest, both trochanters, acetabular margins and symphysis pubis, iliolumbar and sacroiliac ligaments) and that calcaneal spurs and feet and elbow abnormalities were seen in the majority of the individuals. Other less common lesions were: changes at the shoulder-humeral, hands and wrists, tibiofibular region, forearm, femur and patella (Table 13). Their age-matched all-male control group showed small and irregular outgrowths at the iliac crests, ischial tuberosities and/or trochanters and at the calcaneus, olecranon, patella and a small hyperostosis the distal medial humerus. However, in contrast to the extra-spinal enthesopathies observed in the individuals with DISH, the authors described the hyperostosis found in these control individuals as mild and localized (Resnick et al. 1975).

Series A and the control patients were also used in their subsequent study (Resnick et al. 1978) in conjunction with two more series: 40 patients (Series B: 30 male, 10 female; age range: 48-67) determined to have DISH by radiographic criteria (from the Rheumatology Service at the University of North Carolina School of Medicine) and 24 patients (Series C: 16 male, 8 female; age range: 51-81) referred to rheumatologists in Sacramento, California with clinical findings associated with another systemic rheumatic disease and were later found to fulfil the DISH radiographic criteria. Beyond the abovementioned prevalence of extra-spinal enthesopathies in individuals with DISH, the authors also found that the patients from series A showed reduced range of motion in the hip (24%), subtalar joints (19%), shoulders (14%), knees (14%), elbows (10%) and ankles (10%). In series B, 33% of the individuals complained of peripheral bone and joint pain while heel and elbow pain were specifically reported in 23% and 13% of the individuals, respectively (Resnick et al. 1978: 157).

Finally, Utsinger et al. (1976) also based their study in 30 patients (25 male, five female: age range: 50-85) fulfilling the radiographic criteria for DISH. In this case, the extra-spinal manifestations were described as irregular new bone formation, whiskering (pelvis), large bony spurs and severe ligament calcification without providing further description of the size or appearance of the lesions. In this sample, 11 patients (36.7%) complained of peripheral bone and joint pain involving shoulder, elbow, hip, knee, heel and ankle (Table 13). Five additional patients (16.7%) referred single joint synovitis related to either gout or pseudogout. The radiographic studies revealed that every patient had at least one extra-spinal manifestation in the form of irregular bone formation or “whiskering” in the pelvis, large spurs on the olecranon or the calcaneus, severe ligament calcification in the sacrotuberus, iliolumbar and patellar ligaments or paraarticular osteophytes in the sacroiliac joints (Utsinger et al. 1976: 764-766).

While all these studies might suggest that DISH is indeed characterised by spinal and extra-spinal manifestations, the common issue with these studies is that their control samples are either very small or non-existent (Mader et al. 2012). There are, nonetheless, few studies which included control samples. One of these few reports explored the clinical manifestations of DISH by evaluating the association between soft tissue tenderness and DISH in 87 patients with DISH and 65 with osteoarthritis (OA) but without DISH (Mader et al. 2010). The results of this study suggested that DISH patients with severe vertebral bone bridges (judged by the thickness of the ossification on spinal radiographs) had a lower pain threshold than OA patients and a consequent poorer functional status even when adjusting for BMI. At lower spinal bone bridge severity, this correlation was much weaker. Mata et al. (1997) also found that DISH patients have a significantly higher frequency of enthesitis in the shoulder, the medial and lateral epicondyles, the patella and the heel compared to the healthy controls but a similar antecedent of nerve entrapment as the individuals with lumbar spondylosis. Interestingly, DISH individuals in this study were consistently heavier, had been heavier when younger and had a higher BMI, greater chest and waist circumference than the healthy individuals and the patients with lumbar spondylosis. The researchers found that these differences were maintained even when the analysis was adjusted for age and sex thus they suggested that obesity at early age could be a risk factor for DISH (Mata et al. 1997).

Haller et al. (1989) indicated that the of the pelvic regions potentially associated with DISH identified in anteroposterior radiographs of 93 patients with DISH, ten regions correlated more significantly with spinal DISH lesions than with healthy patients or patients with spondylosis deformans. These regions were: symphysis pubis, sacrotuberus ligament, superior portion of the sacroiliac joint, iliolumbar ligament, iliac wing (but not iliac crest), the superior and inferior acetabulum, both trochanters and the ischial tuberosity. The authors found that DISH patients had higher frequencies and bigger pelvic abnormalities than the other groups. However, they also found that the pelvic abnormalities observed in mild cases of

DISH (four contiguous vertebrae affected) were indistinguishable from the spondylosis deformans patients and only slightly bigger than those found in the healthy patients (Haller et al. 1989) and thus these lesions are not characteristic only of individuals with DISH. Finally, in another study evaluating pelvic enthesopathy through CT examinations of 104 DISH patients and 106 age- and sex-matched control patients, it was found that pelvic lesions were more common, robust and prominent in DISH patients (Slonimsky et al. 2016). The authors also found that several enthesopathies and specially the *M. gluteus medius* enthesis had a strong discriminating power between DISH and non-DISH patients. The same research team also found that the prevalence of anterior, posterior and entheseal bridging and ankylosis in the sacroiliac joint was significantly higher in individuals with DISH than in the control sample (Leibushor et al. 2017).

In sum, the prevalence of the extra-spinal manifestations found in this sample is similar to what had been previously published however the lack of proper control samples prevents from truly understanding the relationship between these manifestations and which effect age and or other co-morbidities might have on the presentation of the appendicular enthesopathies or even the spinal. The interaction of all this factors will be briefly explored in section A.4.8.

A.4.6 Co-morbidity between DISH and other conditions in the WM Bass Donated Skeletal Collection

As DISH has been recurrently associated with metabolic and nutrition-related, conditions it was expected that this sample of individuals with DISH would show high prevalence of these conditions. Table 12 and Figure 33 (Section A.3.8) show, 30% of the sample studied suffered diabetes. As stated in section A.1.1, the relationship between DISH and diabetes is still under consideration (e.g. Daragon et al. 1995; el Miedany et al. 2000; Sencan et al. 2005; Westerveld et al. 2014) so, without a control sample to compare this individuals to, it is difficult to assess the significance of this finding. Surprisingly, only two individuals were reported as morbid obese (BMI ≥ 40) however this does not mean that other individuals were overweight (BMI: 25-29.9) or obese (BMI: 30-39.9). Furthermore, the medical records do not make any reference to how long these individuals had been obese. Because of the lack of medical information, no further comment can be made in the widely acknowledged relationship between obesity (or high BMI) and DISH for this sample (Forestier and Rotes-Querol 1950; Utsinger 1985; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Diederichs et al. 2011) nor the impact of early obesity in the development of the condition (Mata et al. 1997; Kiss et al. 2002b).

The metabolic syndrome (MS) is described as a condition characterised by the conjunction of reversible major risk factors for cardiovascular disease and type 2 diabetes. For example: low HDL-cholesterol and increased triglycerides, blood pressure, fasting plasma glucose that lead to weight gain, fat accumulation and large waist circumference (Han and Lean 2016). Exploring the relationship between DISH and MS in this sample, it was found that 25% of the individuals were reported to have suffered diet-related imbalances such as hypercholesterolemia, hyperlipidemia and hypertension. These findings are in agreement with the clinical literature which has also related DISH with several metabolic imbalances (e.g. el Miedany et al. 2000; Kiss et al. 2002b; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Miyazawa and Akiyama 2006).

Interestingly, when pooling together all the metabolic derangements found in this sample, 52.5% of the individuals had at least one nutrition or metabolic-related condition while 47% did not report any metabolic imbalance. It is worth noting that this data is derived from the medical history meaning that it could be possible that a higher number of individuals did have some kind of metabolic imbalance but was not included in the clinical history and it is not known, either, which is the prevalence of these metabolic derangements in the rest of the Bass Collection. Nonetheless, these results are in keeping with the general consensus in the existence of some a link between DISH and different metabolic and constitutional factors (Mader et al. 2013).

Finally, 35% of the individuals (n=14) had some kind of cardiovascular condition. The most common conditions were atherosclerotic cardiovascular disease, heart attack and congestive heart failure. This value is very similar to that reported by Westerveld et al. (2014) who found that 23% of the patients with DISH also had cardiovascular disease. Miyazawa and Akiyama (2006) and Mader et al. (2005) also reported that patients with DISH were more likely to be admitted in the hospital with cardiovascular or cerebrovascular diseases compared to control groups however, in this project, due to the lack of a control group, it is not possible to corroborate this findings.

A.4.7 Food for thought

This last section will explore the some of the contentious points around DISH, mainly about nomenclature and the study description of the extra-spinal manifestations. The last subsection aims to bring together different strands of research to draw a better image of what we know about DISH and which is the type of analysis that could help in increasing our understanding of this disease.

A.4.7.1 Nomenclature

An important issue around DISH is the semantics used to refer different aspects of DISH. As previously indicated, it is extremely common to find the characteristic DISH vertebral outgrowths described as osteophytes. However by definition, vertebral osteophytes are located at the rim of the vertebral endplate and have a horizontal orientation; a configuration which is clearly distinct to what is observed in DISH. Some other authors have used the term “spurs” (Harris et al. 1974), “excrescences” (Resnick et al. 1978) or “new bone formation” (Utsinger et al. 1976); none of these terms are able to describe the nature of the lesion. For this reason, in this project and with a lack for a better word, it was preferred to use the terms of “outgrowths” or “lesions”. However as it seems that the ligaments and connective paravertebral tissues are the elements ossifying in the spinal manifestations of DISH, it would be much more accurate to describe the spinal DISH lesions as *entheseal* lesions (Forestier and Lagier 1971). This is not the first time this term has been used as François et al. (1995: 618), Freemont (2002) and Hannallah et al. (2007) described the prevertebral ossification as being of “enthesopathic nature” however, to the best knowledge of the author, this term has not been used extensively to describe DISH outgrowths. It is worth noting that it is very possible that despite not using this exact nomenclature, most researchers do understand the spinal DISH lesions to be enthesopathies. But then again, by using different nomenclature to describe the spinal and the extra-spinal lesions (spurs and osteophytes *versus* enthesophytes) which have the same nature, we might be unknowingly biasing our own understanding of the condition.

Another similar issue with terminology is specific as to how the extra-spinal manifestations are described. Some authors have used the term “symmetrical” (Crubézy 1989; Mader et al. 2009) while others have used “bilateral” (Resnick et al. 1975). In those papers, it is not defined what is meant by “symmetrical” or “bilateral”. Does symmetrical mean that they need to be of a (roughly) similar size and bilateral mean that both sides are affected but they do not need to be of similar size? This study would then suggest that the extra-spinal lesions observed in individuals with DISH are bilateral but not necessarily symmetrical thus the term ‘bilateral’ would be the most appropriate however the expression of the extra-spinal enthesopathies should be further explored in a bigger sample. In either case, which is the correct one to use? Or are they interchangeable terms? As mentioned above, it would be beneficial for all, palaeopathologists, clinicians and rheumatologists, to use the same agreed nomenclature to define the same pathological changes.

A.4.7.2 Problems with the description and identification of the extra-spinal manifestations

Since Resnick's et al. (1975) systematic description of the appendicular enthesopathy in the individuals with Forestier's disease and the consequent renaming of the disease as diffuse idiopathic skeletal hyperostosis, there has been little questioning of the spinal and the extra-spinal manifestations belonging to the same pathological entity and very few controlled studies evaluating the prevalence of this co-morbidity (Mader et al. 2017). As it was highlighted in Section A.1.2.2, only Mader et al. (2012) and Kuperus et al. (2017) have explored the discrepancies on the diagnostic criteria of DISH and which are the specific features that should, or should not, be included in it. In both cases, the inclusion or exclusion of the extra-spinal manifestations raised discrepancies. This is likely to be related to the fact that most of the articles were uncontrolled and the sample size is very low.

In fact, most of the research that underpins what we know about the extra-spinal manifestations of DISH has been largely based on Harris et al. (1974), Resnick et al. (1975, 1978) and Utsinger et al. (1976), which supports the possibility that the lack of consensus in the appearance of extra-spinal manifestations is related to how they have been studied and reported. In general, the papers describing the presence and appearance of the extra-spinal manifestations give very little detail about the severity of the extra-spinal lesions or to their symmetrical, uni- or bilateral character.

Harris et al. (1974) based their description of the extra-spinal manifestations of DISH on a sample of 34 patients who fulfilled the radiographic criteria for definite and severe DISH: hypertrophic spurs in the dorsal spine predominantly on the right side with at least two bony bridges; absence of other spinal disease which might cause bony bridging (e.g. collapsed vertebra or gross scoliosis); absence of sacroiliitis. The patients were questioned about symptoms referable to the spine and peripheral joints, height and weight were measured, and any clinical evidence of acromegaly, tylosis, or psoriasis was noted. In this sample, the appendicular manifestations in the pelvis, femora and tibiae were described as "fluffy" new bone formation (Harris et al. 1974: 212).

Resnick and colleagues (1975) categorised the extra-spinal manifestations as mild to moderate or moderate to severe without specifying the enthesopathic size ranges considered mild, moderate or severe (Resnick et al. 1975: 514). Furthermore, while a detailed report on the location of the enthesopathies found in all individuals with DISH was produced, the information related to the control individuals is very scarce and it is not clear whether control patients showed entheseal changes at multiple locations (Resnick et al. 1975: 523) Finally, the authors reported that of the 21 patients with DISH, 12 had been involved in occupations with moderate physical activity, six were obese and six were diabetic (it is not clear whether the six obese patients are also the diabetic ones). However there is no information regarding physical activity, obesity and diabetes status for the control group as all the information given is that these control individuals are "age-matched" to the DISH group. Given the close relationship between these three factors and the development of DISH and of extra-spinal enthesopathies, true control groups should also be matched for activity, obesity and diabetes and thus it is not possible to assess how significant the results reported are.

In their subsequent study, the contour of the spine affected by DISH was described as “bumpy” (Resnick et al. 1978: 171). When reporting on the findings related to the extra-spinal manifestations, the authors considered that the lesions were so frequent and distinctive that they could allow a diagnosis of DISH even without or minor axial changes however the descriptions used were still very vague and open to interpretation. For example pelvic abnormalities are described as “bone proliferation or whiskering”, the heel changes as “spurs” and the talar hyperostosis as “beak reminiscent” (Resnick et al. 1978: 164). While in this study, the prevalence of extra-spinal manifestation in the control group are sometimes reported, as the same sample of 21 age matched individuals used in their 1975 study was used, the same problems of comparability and relevance of the results in absence of the biomedical information remain.

Finally, Utsinger et al. (1976) also based their study on 30 patients fulfilling the radiographic criteria for DISH: (1) bridging osteophytes extending over four contiguous vertebral bodies; (2) relatively normal intervening disk space height in relation to age; and (3) absence of apophyseal joint bony ankylosis and absence of erosion, sclerosis, or osseous fusion of the sacroiliac joints. A complete history was obtained and physical examination including spinal flexion range and sacroiliac tenderness were included. Regarding the reporting of the extra-spinal manifestations, it is no clear whether any of the individuals showed bone changes at more than one location. Furthermore, prevalence of entheseal changes in the shoulder, hip, knee and ankle is unknown as the only information reported is refers to reported pain thus it is not clear if this pain was related to bone changes. Finally, in this study there was no control group to compare the prevalence of the different entheseal changes found in the individuals with DISH (Utsinger et al. 1976).

Despite these examples, some researchers have tried to be more accurate in their description of the extra-spinal manifestations. For example, Crubézy (1989) was the first one to describe DISH’s extra-spinal manifestations, involving the calcaneus, patella or olecranon, as symmetrical, with the entheseal new bone having a well-defined cortical margin and measuring at least 3mm. Vidal (2000) followed Crubézy and Crubézy-Ibanez’s (1993) example thus also describing the enthesopathies found in the calcaneum, olecranon and patella as symmetrical and very developed in the individuals with DISH adding that these four individuals also showed hyperostotic changes in the pelvis and tibia. Finally, Kacki and Villotte (2006) also considered that the enthesopathies had to be symmetrical but set the threshold at 2mm. The imposition of a minimum size is paramount because peripheral enthesopathy has been closely linked to the combined effects of microtraumatisms and age (Crubézy 1989). Neither Vidal (2000) nor Kacki and Villotte (2006) mentioned the character of the entheses in the non-DISH individuals. It is also important to highlight that while giving a definite threshold, these papers do not report on the prevalence of the extra-spinal manifestations in the individuals with or without DISH.

It is noteworthy that despite the lack of control samples – in the four studies only Resnick et al. (1975, 1978) used a relatively small control sample – the presence of the extra-spinal manifestations has been deemed so constant that, even in absence of proper spinal radiographies, their presence could be considered as suggestive of DISH (Utsinger et al. 1976: 766; Resnick et al. 1978: 164). If we want to understand the relationship between the spinal and the extra-spinal manifestations of DISH there is an imperative need to improve our methodology. The method to measure the lesion needs to be standardised and researchers need to be much more accurate at not only describing and measuring these enthesopathies but also to reporting the individuals affected and the location and the size of the lesion. To the knowledge of the author, this is the first time that the character and size of the enthesopathies for each individual has been reported.

A.4.7.3 Rethinking DISH

It is not the aim of this subsection to redefine DISH since this should be done in a multidisciplinary manner. However it will highlight some of the questions that should be considered and some of the links that should be explored.

Firstly, the relationship between the spinal and the extra-spinal manifestations of DISH. As previously mentioned, this project has not been able to find a positive correlation between the two types of manifestations which reportedly belong to the same condition. While individual variability is not altogether surprising the research that underpinned this association was lacking sufficient control samples and accurate reporting of the characteristics of the extra-spinal enthesopathies. The fact that DISH was primarily defined as the anterior ossification of the spine and that there is a significant absence of consensus in relation to the extra-spinal manifestations, could lead to a new diagnostic criteria for DISH considering the spinal lesions, as described in here, as pathognomonic changes and include the bilateral/symmetrical extra-spinal enthesopathies bigger than 2-3mm as a possible co-morbidity. This diagnostic criteria would not take into account the fact that both types of manifestation are of enthesopathic nature and, while the aetiopathogenesis of DISH is far from clear, enthesopathies, in general, have been related to age, obesity and metabolic factors and trauma or microtrauma (e.g. Julkunen et al. 1971; Resnick and Niwayama 1983; Freemont 2002; Wearing et al. 2006; Alves Cardoso and Henderson 2010; Mazières 2013).

With this issue in mind, maybe the term of “bone formers” described by Rogers and colleagues (1997) should be recovered to define those individuals who have a tendency to build up new bone in the presence of a certain type of stimulus. In fact, patients with DISH have been previously described as suffering from an ossifying diathesis and as having the propensity to develop ossifications to surgery (Resnick et al. 1978: 185; Fahrer et al. 1988). Finally Mays (2016) found a positive association found between the metacarpal cortical thickness and the ossification of the anterior longitudinal ligament when age, sex and other confounding factors were controlled for. The author suggested that the tendency for spinal ossification was primarily associated with a lesser resorption at the endosteal layer of the bone.

In this case, how do we define DISH? Is it then the presence of antero-lateral spinal enthesopathy and/or the presence of symmetrical appendicular enthesopathy measuring more than 3mm at the posterior and plantar aspects of the calcaneus, olecranon, base of the patella, ischial tuberosity, iliac crest and/or femoral trochanters? This definition would be significantly looser than the ones used until now, would not require the presence of the “characteristic” spinal ankylosis and therefore would skew the prevalence of the disease. Thus, possibly it would be better to retain the presence of spinal changes as a corner-stone of the diagnostic criteria of DISH and report the presence and characteristics of the extra-spinal manifestations (age and biomedically-matched DISH and control groups) to facilitate the investigation of what features actually define this condition. How can or should we differentiate between the individuals who develop the diffuse ossifications spontaneously or those who develop it after an intervention? Can DISH (understanding it as a diffuse ossifying diathesis) develop after a surgical intervention? And if so, are the molecular pathways involved in the “spontaneous” development of DISH the same as those pathways activated by the surgical intervention?

Research on molecular signalling pathways has suggested that factors directly or indirectly controlling and modulating osteogenesis might be affected in individuals with DISH. For example, a study reported that the levels of circulating functional Dickkopf-1 (DKK-1), an inhibitor of the osteoblastogenesis from the Wnt signalling pathway which is known to have an important role in maintaining the osteoblast activity and maintaining the body bone mass (Daoussis and Andonopoulos 2011), are significantly lower in patients with DISH (diagnosed following Utsinger’s et al. 1976 criteria) compared to sex and age-matched controls (Senolt et al. 2012). However in another cross-section study including patients with DISH and age and sex-matched healthy controls, no difference in levels of DKK-1 were found between the two groups (Aeberli et al. 2011). This apparent discrepancy could be explained by the fact that while levels of circulating DKK-1 might be similar or lower in patients with DISH compared to the control group, the levels of *functional* DKK-1 are lower in the first group; this was also observed in ankylosing spondylitis patients (Daoussis and Andonopoulos 2011). It has been also observed that mechanical stress can induce the production of endothelin-1 and prostaglandin I_2 in OPLL cells (cells involved in the ossification of the posterior longitudinal ligament), which, in its turn and through different molecular mechanisms, can promote the ossification of the posterior longitudinal ligament (Ohishi et al. 2003; Iwasawa et al. 2006). Other molecules identified to be involved in the pathological ossification of spinal ligaments are the bone morphogenic protein-2 (BMP-2) and the nuclear factor κB (NFκB) (Kosaka et al. 2000; Tanaka et al. 2001). Nuclear factor κB (NFκB), possibly activated by environmental factors, proved to be increased in patients with DISH or ossification of the spinal ligaments compared to patients without ossification of the spinal ligaments (Kosaka et al. 2000). As all these studies are focused in understanding the pathways related to the ossification of spinal ligaments and it would be interesting to investigate their activation pattern in the formation of extra-spinal enthesopathies. Maybe in this case it could be possible to say that the spinal and the extra-spinal enthesopathies are molecularly related or are two distinct entities, at least at the cellular level.

And finally, while it seems that mechanical stress can induce the ligament ossification, we still need to understand how obesity or metabolic imbalances as well as age or even surgery influence the subcellular metabolism to induce the entheseal changes observed in DISH. Do all of these intrinsic and extrinsic factors use the same pathway or what do they have in common to be able to activate the same type of bone formation?

A.5 SUMMARY OF PART A

As this part has shown, diffuse idiopathic skeletal hyperostosis is not a straight forward, easily described and predictable condition. In fact, beyond its enthesopathic nature and its probable relationship to metabolic derangements, its aetiology, pathogenesis, co-morbidities and even its diagnostic criteria are still a topic of intense debate in the clinical sphere.

The analysis of the individuals from the WM Bass Donated Skeletal Collection corroborated that the widely accepted spinal manifestations involve the anterior surface of the vertebral body. At the right side, the raised ossification is usually continuous and more voluminous than at the left side which, if present, the ankylosis is usually a flatter paravertebral ankylosis. Also in keeping with previous research, it was found that the most commonly affected vertebrae by the main ankylosis were between the 7th and the 11th thoracic vertebrae however some individuals could show the entire thoracic vertebral section affected and even cervical or lumbar involvement, although these were less common. In any case, at either side of the complete bridging ankylosis, the vertebrae can show developing ossifications in the form of touching or interlocking outgrowths raising from adjacent vertebrae and beyond these, solitary vertical outgrowths suggesting the pattern of development of these lesions. In all cases, the lesions were found to be rooted at the central section of the vertebral body, have a vertical orientation and overtake the intervertebral disc. These ossifications have an external compact cortical layer and a well-organised internal trabecular bone seemingly in continuity with the vertebral body’s own internal structure. Finally, it was found that despite always being located at the anterior surface of the vertebral body, the location of the continuous outgrowth shifts from the central third to the right half and finally to the lateral thirds of this surface, thus following the route described by the descending aorta. As noted in section A.4.4, this distribution does not agree with the description that the spinal ankylosis is the ossification of the anterior longitudinal ligament but rather the ossification of the paravertebral connective tissue which would include some of the anterior longitudinal ligament’s fibres as well as the continuous perivertebral fibrous sheath, formed by short fibres inserting into two adjacent vertebrae and extending in front of the disc, and the peripheral part of the disc (Forestier and Rotes-Querol 1950: 329, Forestier and Lagier 1971: 69).

The relationship between discarthrosis and DISH has also raised a significant debate with some researchers considering that their co-morbidity is acceptable and, to a certain point, expected since both conditions are more prevalent in older individuals while some researchers considering that their co-morbidity is not possible. The results obtained from the first part of this project suggest that, in the same spine, the co-existence of these two conditions is possible and is more prevalent in the lumbar section of the spine. However it is worth noting that unlike the vertebrae affected by discarthrosis, those affected by DISH do not tend to show any degeneration of the endplate and only when there is a combination of discarthrosis and DISH in the same vertebrae it is likely to see the DISH outgrowths accompanied by endplate degeneration. In these cases, it is possible that the degeneration of the intervertebral disc had started before the arrival of the DISH ankylosis and thus that DISH acts as a protection against the age-related degeneration of the endplate.

Since 1975, when the extra-spinal manifestations of DISH were firstly described, their inclusion in the description of DISH has not been questioned and yet there is a significant lack of research exploring the relationship between the spinal and the extra-spinal manifestations of DISH. The results presented here do not support their association however it is possible that the significant interpersonal variability in this relatively small sample size might have biased the results. Nevertheless while the results from the sample from the Bass Collection are comparable to those reported in previous studies the absence of age and sex-matched studies involving patients with DISH, patients with discarthrosis and healthy individuals prevent exploring the aetiology and the factors involved in the development of the both types manifestations. Finally, as the spinal and the extra-spinal manifestations of this condition are of enthesopathic nature, in the last section, it was suggested that further clinical and palaeopathological research needs to be undertaken to learn more about the aetiology, characteristic manifestations and co-morbidities of this condition. For the following part of this thesis where the prevalence of DISH will be explored in English and Catalan historical population from the Roman to the post-medieval period, the original description of DISH – as a condition being defined by the presence of the spinal ankylosis – will be maintained. The relationship between the spinal and the extra-spinal manifestations, as well as symmetrical or bilateral character of the latter one, will be further explored with a significantly larger sample.

In regards to the co-morbidity of DISH with other metabolic conditions, the results obtained here mimic the clinical research since they show that more than half of the individuals with DISH also suffered at least one type of metabolic derangement such as obesity, type 2 diabetes, high blood tension or hypercholesterolemia. The individuals from the Bass Collection showed a high prevalence of cardiovascular conditions which, clinically, have also been found to be prevalent in individuals with DISH and are possibly related to the high prevalence of the metabolic imbalances.

So finally, taking the results from this first part forwards and to the second part of this project, all stages of DISH (isolated outgrowths, interlocking and bridging ossifications) will be recorded. The relationship between these lesions and the degeneration of the endplate will be further explored; a low prevalence of co-morbidity between DISH and discarthrosis is expected throughout, except at the lumbar level. And finally, despite the fact that archaeologically it is not possible to identify the metabolic derangements abovementioned, the correlation between DISH and other nutrition and metabolic-related conditions, such as gout, rickets and scurvy, will be recorded and used as a proxy for diet.

PART B: DIFFUSE IDIOPATHIC SKELETAL HYPEROSTOSIS IN THE ARCHAEOLOGICAL CONTEXT

In this second part of the project, the aim is to investigate the prevalence of DISH through time in Catalonia and England. In here, an overview of DISH in the archaeological context will be given. This introduction will be followed by the method to record the archaeological human remains, DISH and different metabolic and nutrition-related conditions identifiable in human remains. Then there will be a comparison between the two regions in regards to their chronology, the description of the sites chosen for analysis and the change of the diet across time for the two regions. Finally, macroscopic results and the stable isotope data obtained from the Roman sites of Baldock (Hertfordshire) and Santa Caterina (Barcelona, Catalonia) will be presented and discussed in relation to previously published data.

B.1. DIFFUSE IDIOPATHIC SKELETAL HYPEROSTOSIS IN THE ARCHAEOLOGICAL RECORD.

B.1.1 Cases of DISH in archaeology

Diffuse idiopathic skeletal hyperostosis has been described in archaeological remains dating from prehistory to the modern times. One of the main problems in archaeology and, especially in the analysis of human remains, is the level of completeness and the degree of preservation of the remains. However, when the human remains are well preserved, the diagnosis of DISH is considered to be straight forward and uncomplicated (Crubézy and Trinkaus 1992; Rogers and Waldron 1995).

Table 14 shows a summary of studies carried out on archaeological samples from different time periods and geographical locations. It is important to notice that the diagnostic criteria applied are very variable and not always specific for archaeological human remains (e.g. Resnick and Niwayama (1976)) and the definition of the age range tends to be very vague (e.g. “adults”). The combination of these two factors thwarts the direct comparison of the results obtained from different sites (van der Merwe et al. 2012) and thus the drawing of wider conclusions about the prevalence of DISH in different social strata and in different types of community becomes very complicated.

Table 14: Prevalence of DISH in different archaeological populations

Reference	Region	Period	Sample size	Diagnostic criteria	Age range	Prevalence (%) Male	Female	Pop. Av.
Rogers et al. (1985)	England	Romano-British	81	NS	Adult			0
	England	Anglo-Saxon	121		Adult			2
	England	Medieval	303		Adult			2.6
	England	Post-Medieval	54		Adult			3.7
Waldron (1985)*	England	1140 - 1540	35	NS	-			8.6
Kramar et al. (1990)	Switzerland	Early Medieval	27	NS	Adult			3.7
Mays (1991)	England	Late Medieval	67	Rogers et al. (1985)	Adult			13.4
Arriaza (1993)	Chile	7000 – 530 BC	72	Resnick et al. (1975)	>40			1.4
		500 BC – 300 AD	54		>40			1.9
		1000 – 1530 AD	214		>40			1.4
Arriaza et al. (1993)	Meriotic Nubia	2350 BC – 1750 AD	134	NS	Adult	18	7	13.7
Cunha (1993)	Portugal	c.12th – 15th	44	Resnick and Niwayama (1976)	>40	28	50	11.4
		c.19th-20th	51		>40	50	48	
Maat et al. (1995)	Holland	1375 – 1572	179	Rogers and Waldron (1995)	Adult	10.3	3	
Rogers and Waldron (2001)	England	13th – 16th c.	272	Rogers and Waldron (1995)	Adult	6.3[b]		
Jankauskas (2003)	Lithuania	1st mill. AD	142	Resnick and Niwayama (1976)	Adult			9.1±2.9
		2nd mill. AD	316		Adult			13.3±1.9
		1st & 2nd mill. AD	458		Adult	18.0±2.4	2.6±1.3	
Oxenham et al. (2006)	Japan	1500-300BCE	14	Rogers and Waldron (1995)	Adult	14.3		
		500-900 CE	39		Adult	0	0	0
Kacki and Villotte (2006)	France	1480 –18th c.	305	Utsinger (1985)[c]	>50	18.8	2	
Müldner and Richards (2007a)*		13th – 16th c.	217	NS	-			3.3

Cont…

Table 14 cont...

Verlaan et al. (2007)*	Netherlands	275 – 1795 AD	42	-[d]	Adult			40.4
Mosothwane and Steyn (2009)	Botswana	8^{th} – 14^{th} c.	21	NS	>15			4.8
Paja et al. (2010)	Hungary	10^{th} – 18^{th} c.	6966	Resnick and Niwayama (1976)	Adult			0.17
Kim et al. (2012)	Korea	16^{th} – 18^{th} c.	5/13[e]	Combined criteria[f]	20 – 35	0	0	
			22/15		35 – 50	4.5	0	
			21/12		>50	13.4	0	
			54/42		Subtotal	7.4	0	
			96		Total			4.17
Smith et al. (2013)	Tennessee	13^{th} – 16^{th} c.	389	Crubézy and Crubézy-Ibáñez (1993)[g]	Adults	1.2		0.8
Patrick (2014)	England	Medieval	85*	-[h]	>45	17.2		
			174			8.7		
Mays (2016)	England	Post-medieval	137	Julkunen et al. (1971)	>40	14.5	5.9	

NS: not specified. Pop. Av.: average of DISH within the studied population.*Include monastic populations. [a] The real sample size is of 178 but 67 were the individuals whose spines were assessed. [b]The values from the different sites have been averaged. [c]The authors introduced modifications to the original DC such as discontinuations at the ossification and the enthesophytes must be bigger than 2mm (after Crubézy (1989). [d] Method: ossification of at least four contiguous spinal levels and/or multiple enthesopathies of the appendicular skeleton. [e] Number of males and females respectively. [f]Combined criteria: Resnick et al. (1975), Resnick and Niwayama (1975), Rogers et al. (1985), Rogers and Waldron (1995, 2001). [g]Modified method: definitive DISH with 3+ effected vertebrae; possible DISH with 2+ affected vertebrae. [h]Method: single-sided fusion of at least three consecutive thoracic vertebrae and additional extra-spinal enthesopathies (Patrick 2014:85).

Besides these population studies, DISH has been described in a number of individual cases. Crubézy and Trinkaus (1992) described Shanidar 1, a Neanderthal individual from the Upper Palaeolithic, as a case of DISH with multiple traumatic lesions and widespread degenerative joint disease. Trinkaus and colleagues (2008) presented another Neanderthal individual, Kiik-Koba 1, as a case of DISH with a pedal phalangeal trauma and age-related changes. Canci et al. (2005) reported a case of DISH in a 40-50 year old female from sixth century living in the Hellenised Southern Italian village of Montescaglioso. In this case, the authors suggested that the female also suffered of melorheostosis, a rare soft tissue sclerosis dysplasia involving the skeleton and the surrounding soft tissue. Also in this village of Montescaglioso, at medieval cemetery of St Angelo Abbey, the remains of man of an estimated age-at-death between 25 and 35 were recovered and diagnosed as DISH, widespread enthesopathies and a possible pelvic trauma (Reale et al. 1999). From the 13th century Basque Country, three monks considered to be relatives also showed spine ankyloses and gross extra-spinal osteoarthritis suggestive of DISH and extensive osteoarthritis possibly related to the obese status and the type of activities these individuals might have undertaken (De la Rúa and Orúe 1992). In the family of the Grand Dukes of Medici from the 15th and 16th century Italy, DISH in combination with gout has been diagnosed in Grand Duke Cosimo I and in Grand Duke Ferdinand I (Villari et al. 2009; Giuffra et al. 2010). And finally, in conjunction with osteosarcoma, DISH was diagnosed in a 19th century 45+ years old male from Wolverhampton (Ortner et al. 2012). While these case studies do not provide information about the prevalence of DISH in the population, they are very important as they possibly are the only available resources to investigate the co-morbidity of DISH with other conditions (such as gout and obesity), a relationship that will be explored in this thesis.

B.1.2 Diagnostic criteria for archaeological human remains and related difficulties

Resnick et al. (1975) is the most applied method for the diagnosis of DISH in archaeological human remains. However, this method was developed for the clinical practice and is based on the radiographic appearance of the spinal ossification. Its application to archaeological material could prove problematic and induce underestimation of the condition because as it suggests that four vertebrae should be involved in the ankylosis, only the very advanced cases of the condition are identified. Furthermore, it does not allow for the co-occurrence of DISH and discarthrosis, a co-morbidity extensively explored and discussed in sections A.3.4 and A.4.5.

Rogers and Waldron's (2001) is the other diagnostic criteria widely used for archaeological human remains. Unlike Resnick and colleagues' (1975) criteria, this was specially developed for archaeological human remains. Compared to Resnick and colleagues' (1975) method, this criteria slightly less strict since it requires at least three vertebrae affected (with or without complete ankylosis) to provide a definite diagnosis. Despite this, the requirement of three vertebrae could also potentially lead to an underestimation of the prevalence of the condition. When comparing these two methods, van der Merwe et al. (2012) found that Roger and Waldron's (2001) method allowed the identification of more individuals with "definite DISH" individuals compared to Resnick and Niwayama's (1976) criteria and suggested that this phenomenon was due to the fact that

Roger and Waldron's did not consider the presence of disc degeneration to be an excluding factor for the diagnosis of DISH (van der Merwe et al. 2012) as both criteria consider 'definitive DISH' when at least four vertebrae are involved in the ankylosis and 'possible DISH' when three vertebrae are affected.

Mimicking the controversy around the inclusion or exclusion of the extra-spinal manifestations in the clinical diagnostic criteria of DISH, in the archaeological context, these manifestations are also treated differently depending on the chosen criteria. For example, Crubézy (1990) and Kacki and Villote (2006) considered that for the enthesophytes to be considered part of the diagnosis, they had to be symmetrical and larger than 3 or 2 mm, respectively, and be present, at least, at the calcaneal tuberosity, the base of the patella and the olecranon. These enthesopathies had to have a well-defined cortical margin and the joints were to be free of inflammatory conditions. Meanwhile, Roger and Waldron (2001), while considering that the lesions (patellar and olecranon tufting, heel and tibial tuberosity spurring and ossification of the *ligamentum flavumI*) had to be symmetrical but did not set a threshold over which the enthesopathy could be considered as part of the condition.

As previously indicated, traditionally, a complete ankylosis of at least three vertebrae has been considered a requisite for a positive diagnostic of DISH. However, Rogers and Waldron (2001) and Kacki and Villote (2006) suggested that the minimum of three or four vertebrae showing hyperostosis (respectively) did not have to be completely ankylosed to still be able to safely diagnose DISH. Kacki and Villotte (2006) applied this method on the Cemetery of the Convent of the Soeurs Grises of Beauvais (Oise, France) from the 15th-18th century. Although, this criteria has not been applied to other samples, it should be expected that, since a complete ankylosis is not needed for a positive diagnosis, the calculated prevalence rates would be higher than when applying other, more restrictive, criteria.

Table 15 shows a summary of the diagnostic criteria that have been specifically designed for archaeological human remains. Similarly to what was previously observed with the clinical diagnostic criteria, the application to the same sample of methods that consider different features will produce dissimilar prevalence rates of DISH (van der Merwe et al. 2012). This means that when comparing different studies, the possible biases introduced by the application of different diagnostic criteria should be considered. With the exception of Kacki and Villote (2006), when comparing these studies to the results obtained in this project, the prevalence reported in these studies will have to be compared to the prevalence of stage 4 of development DISH (more than two vertebrae involved in the ankylosis) described for this project.

Table 15: Summary of the characteristics of the different diagnostic criteria for DISH

		Crubézy (1989)	Crubézy and Crubézy-Ibanez (1993)	Rogers & Waldron (1995)	Kacki & Villotte (2006)
	Criteria based on	Utsinger (1985)	Human remains	n/a	Utsinger (1985)
Spinal	Antero-lateral flowing ossification	Yes	Yes	Yes	Yes
Spinal	Ankylosis discontinuity[a]	n/a	n/a	Yes	Yes
Spinal	Unilateral	Right	Yes	Right	n/a
Spinal	Definitive DISH[b]	3 in low thoracic	3 in low thoracic	≥4	≥4
Spinal	Poss./prob. DISH[c]	2 in thoracic	2	<4	≥2
Spinal	Cervical involvement	Yes[d]	n/a	n/a	n/a
Spinal	Lumbar involvement	Yes[d]	n/a	n/a	n/a
Spinal	Apophyseal joint	Preserved	Preserved	Preserved	Preserved
Spinal	Intervert. disc space	Retained	Retained	Retained	Retained
Spinal	Degenerative disc disease	n/a	Yes[d]	No	No
Spinal	Discarthrosis	n/a	n/a	No	n/a
Spinal	Sacroiliac joint	AS bridging	AS bridging	AS bridging	Unaffected
Extra-spinal	Enthesophytosis	Yes (>3mm)	Yes	Yes	Yes (>2mm)
Extra-spinal	Presence	Symmetrical	Yes	Yes	Yes
Extra-spinal	Patella tufting	Yes	Yes	Yes	Yes
Extra-spinal	Heel spurs	Yes	Yes	Yes	Yes
Extra-spinal	Olecranon tufting	Yes	Yes	Yes	Yes
Extra-spinal	Tibial tub. Spurs	n/a	No	Yes	n/a
Extra-spinal	Lig. flavum ossif.	n/a	n/a	Yes	n/a
Extra-spinal	Sacroiliac lig. ossif.	n/a	n/a	n/a	n/a
Extra-spinal	Iliolumbar lig. ossif.	n/a	n/a	n/a	n/a

The shaded features are the ones which are shared amongst all the criteria. n/a: non-applicable: the diagnostic criterion does not mention this parameter. [a]: the criteria accepts that some bone bridges might not be completely fused. [b]: number of vertebrae required to issue a definitive diagnosis of DISH. [c]: number of vertebrae required to issue a probable or possible diagnosis of DISH [d]: the criteria observes the possibility of the feature to happen.

B.1.3 DISH and diet: monastic and status studies.

As previously reviewed (section A.1.3), there seems to be an agreement about the relationship between DISH and obesity and, hence, diet (Forestier and Rotés-Querol 1950; Utsinger 1985, Sarzi-Puttini and Atzeni 2004, Diederichs 2011). In archaeology, this relationship has been investigated by comparing the prevalence of DISH in monastic communities versus layfolk (Waldron 1985; Rogers and Waldron 2001; Verlaan et al. 2007; Patrick 2014: 102) or in families or communities known to have had some high status individuals (Jankauskas 2003; Giuffra et al. 2010).

Waldron (1985) was the first to study the relation between DISH and monastic communities at the cemetery of Merton Priory. In this study, it was found that monastic and wealthy lay people (buried inside the church) showed significantly higher prevalence of DISH than the layfolk buried outside the church. According to the author, that meant that the medieval monks ate much more than what they had been allowed according to the monastic laws and named this phenomenon “The Monastic Way of Life”. In fact, his results and argumentation agreed with some contemporary records which suggest that monastic diet included significant amouts of meat and fish (Waldron 1985). This conclusion was also shared by Verlaan and colleagues (2007) who studied the abbey court (Pandhof) of the city of Maastricht, where, presumably, clergymen and high status individuals were buried. Their results show that 17 out of the 39 adult individuals (40.4%) showed ossifications of, at least, four vertebrae and multiple extra-spinal enthesophytosis. And in an interdisciplinary approach to investigate the truthfullness of the stereotype of the “obese medieval monk” in three London monasteries, Patrick

(2014) concluded that monks were three times more likely to develop DISH and over five times more likely to develop one form of obesity-related osteoarthritis compared to the layfolk (Patrick 2014: 152). Furthermore, the author argued that monastic communities showed a greater proportion of overweight individuals compared to the secular communities, but the small sample size prevented to assert the relationship between monastic lifestyle and obesity (Patrick 2014: 117).

A word of caution was given by Mays (2006) who considered that the reports showing this apparently overwhelming relationship between the monastic life and DISH were based on relatively small number of samples and without proper non-monastic age-matched control groups. The author indicated that more exhaustive analysis should be carried out before we can categorically assert that the monastic communities had a richer diet, comparable to that of the wealthy lay individuals, than the expected one if the monastic dietary guidelines were upheld. Furthermore, it seems that DISH is more prevalent in older male individuals, thus focusing the study on the monastic community is likely to find an overestimated prevalence of this condition due to the inherent sex and age bias of the sample (Mays 2006). Sadly, there has not been much further research in this topic.

Quintelier et al. (2014) attempted an isotopic analysis of some of the individuals buried in the post medieval Carmelite Friary of Aalst in Belgium. The authors selected 39 adult individuals (15 males and 14 females) as well as the individuals diagnosed with DISH (all males). Their results seem to show differences in dietary patterns depending on sex, however the authors suggest that this could be due to the small sample and that the male sample consisted in lay and monastic individuals. Nonetheless, their data indicated variation in diet depending on burial location. For example, the individuals buried in the cloister or inside the church (friars and wealthy townspeople respectively) showed similar isotopic values suggesting that these communities had an isotopically similar diet. Conversely, the individuals buried in the garth (typically less afluent lay people) showed lower $\delta^{13}C$ and $\delta^{15}N$ values, suggesting a diet poor in marine products. Interestingly, the authors found no statistically significant differences on the isotopic values when comparing DISH and non-DISH individuals.

Another study investigating the relationship between DISH and diet using isotopic analysis is that of Spencer (2008) who analysed a total of eight late medieval monastic and non-monastic sites. Similarly to Quintelier's et al (2014) results, the author found no statistically significant relationship between the DISH status (DISH vs non-DISH) and $\delta^{13}C$, however individuals with DISH seemed to have higher values of $\delta^{15}N$ than individuals without DISH, suggesting that the individuals with DISH had a higher meat or fish intake. While this pattern remained true when only the monastic sites where evaluated, it was not observed when males and females were studied separately. Furthermore, the analysis found no statistically significant isotopic differences between monastic and non-monastic groups even when, based on the documentary and historic sources, monastic fasting adherence and specific food regulations and food availability for the layfolk should have influenced the isotope results. However the sample size for this study was too small to indentify any difference between the DISH and the non-DISH individuals (Spencer 2008).

One last analysis of the isotope signature of DISH individuals was carried out by Müldner and Richards (2007a) on four individuals with DISH from the late medieval Gilbertine priory of St Andrew, Fishergate in York. The authors found that while the isotopic signature of individuals with DISH was similar to that of the male individuals without DISH, the affected individuals showed higher carbon and nitrogen values compared to the male average ($\delta^{13}C$: -18.9‰ and $\delta^{15}N$: 13.0‰) which suggested a rich diet with a significant input of marine resources (Müldner and Richards 2007a).

From these three studies, different questions are open: first, is diet the only factor involved in the development of DISH or are there other predisposing factors that might explain the prevalence inequality between monks/wealthy townspeople and poor people? And second, is the method of assigning diet styles according to the isotopic values sensitive enough to be able to identify the subtle differences in similar diets, particularly if the collagen is from bulk samples which represents a longer period of life? It should be taken into account that the sample size is relatively small and, to the knowledge of the author, these are the only results published to date attempting to analyse the relationship between DISH and dietary isotopic values. It is possible that studies with a bigger sample size and the combination of comparable studies based on standarised methods and procedures, will allow for a better understanding of this relationship.

B.1.4 Summary

Diffuse idiopathic skeletal hyperostosis is a well-recognised condition in both the clinical and the palaeopathological fields, but its recent identification as a condition means that our understanding of DISH is still limited. Furthermore, there is still some confusion to identify the most suitable diagnostic criteria for each type of sample, which, combined with the non-identification of the early stages of DISH development, results in the difficulty to accurately evaluate the prevalence of the condition in modern as well as in ancient populations.

Unlike other conditions in archaeology or the study of DISH from the medical point of view, there are extremely few studies specifically designed to increase our understanding of DISH in the archaeological record other than just reporting the prevalence of the disease either in different regions or across time periods for a region. Furthermore, the use of several different and non-comparable diagnostic criteria, the generally small sample size as well as the poor characterisation of the type of sample also prevents the comparison of the results obtained in different studies.

In this sense, the following chapter will delineate the methods and criteria used to define DISH and its manifestations, co-morbidities and differential diagnosis.

B.2 METHODS

To determine the prevalence of DISH in the different archaeological populations, an osteological analysis was carried out. The first step in the recording of the human remains was the evaluation of the spine, to ensure that enough vertebrae were present for confident diagnosis. Afterwards, a sex assessment and age estimation was performed bearing in mind that only adult individuals were considered since DISH is only present in this segment of the population. It is important to note that the methods utilised and the amount of data collected per each individual will depend on the level of completeness and preservation of the remains. Then, a complete evaluation of the spinal and the extra-spinal manifestations carried out and finally a palaeopathological analysis was executed with special emphasis in the diet or metabolism-related conditions. The design of the recording form can be found at Appendix 3.

B.2.1 Human remains inclusion criteria

The findings at the WM Bass Donated Skeletal Collection which corroborated previous research suggest that the vertebrae more commonly affected by DISH are between the 7th and the 11th thoracic vertebrae (see section A.4.4 for further discussion). Thus it was considered that to allow reliable recording the spine of each individual included in the analysis had to fulfil the following criteria: **the anterior portion of at least three thoracic vertebral bodies, preferably from the lower half of the thoracic portion of the spine, must be evaluable.**

If some of these vertebrae were present but considered poorly preserved or could not be assessable, the spine was not considered usable for the analysis.

This criteria was defined to standardise the sample and reduce the probability that inter-site differences in preservation of the spine affected the interpretation of the data as *only* the individuals that fulfilled the criteria were included in the analysis. This criteria was applied even when individuals showing less than three lower thoracic vertebra but with clear signs of DISH were found to avoid over-representation of the condition. This stringent criteria had a real impact in the sample size as, usually a third of the adult individuals were well preserved well enough (see Tables 23 and 24).

B.2.2 Osteological analysis

To elucidate the relationship between DISH and diet and other diet-related conditions an accurate and age estimation and sex assessment of all adult individuals with a usable spine was needed. In this section, the osteological methods that have been applied are described.

B.2.2.1 Age estimation

Because one of the aims of this project was to study the distribution of DISH throughout the different populations, the accurate age estimation of the maximum number of individuals was imperative. The differentiation between adults and juvenile individuals was established according to the epiphyseal fusion. If the long bone epiphyses were not fused, the individual was classified as juvenile and, if fused, the individual was classified as adult. The sternal epiphysis of the clavicle and the iliac crest, which are late fusion epiphyses, were not considered for this classification.

The age estimation of the adults was carried out by applying transition analysis (Boldsen et al. 2002) using a combination of pubic symphysis, auricular surface and cranial suture closure features. To process the data, the ABDOU Age Estimation software developed by Boldsen et al. (2002) was used. This method was chosen because it avoids the mimicry effect and provides a better age estimate than the classical age estimation methods (Bullock et al. 2013). The other advantage of this method is that, because of the high subdivision of these three areas, it is still applicable when there is fragmentation of the diagnostic areas.

Originally it was intended to apply dental attrition age estimation method (Brothwell 1981) to all the populations as it is claimed to be applicable to all the populations from Roman to the late medieval period but not to the post-medieval population. This selective application of the method was based on the assumption that, in the past, molars were more prone to wear due to the abrasive particles within the food (Mays et al. 1995; Whittaker 2000: 87). As diet softened in the post-medieval period, the rate of wear would therefore be reduced and making this age estimation method less precise (Mays 2002). The application of this method would also assume that the rate of wear in these two populations was similar for all the time periods. From the analysis of the dietary habits of these two populations (see Section B.4) it is not possible to deduce whether the rate of wear would have been similar or different. However the application of Brothwell's (1981) in some Catalan samples showed that the estimated age at death using transition analysis and dental attrition were not broadly comparable (Table 16) and the scope of the project did not permit the calibration of the dental wear for all the different population using Miles' (1963) method. Because of this, to ensure consistency in age estimation throughout all the populations analysed, only transition analysis was applied. If this method was not applicable due to preservation constrains, the individual was been classified as *adult.*

Table 16: Comparison between dental attrition and transition analysis age estimation methods in some Catalan collections

Site	ID	Dental age	MLE* age
Santa Caterina	002-00-706	17 – 25	47.6
	002-00-708	25 – 35	26.7
	002-00-719	17 – 25	71.7
	002-00-733	25 – 35	35.4
	010-04-T14	17 – 25	76.6
	010-04-T15	25 – 35	72.4
	010-04-T18	17 – 25	70.8
	072-86-B1.119	17 – 25	35.0
	072-86-B2.50	25 – 35	63.3
	072-86-B2.62	17 – 25	39.2
	072-86-B3.59	25 – 35	37.5
	072-86-B3.87	17 – 25	30.5
Sant Esteve de Granollers	88	25 – 35	28.6
	1704	25 – 35	28.8
Sant Pere de Terrassa	6	25 – 35	20.1
	40	25 – 35	71.8
	259	25 – 35	75.4
	415	17 – 25	27.1
	635	25 – 35	62.5
	680	17 – 25	23.7
	769	33 – 45	20.4
	775	25 – 35	26.1

*MLE: maximum likely estimate age as indicated in the output of the transition analysis software at 95% likelihood.

Age categories have been described to facilitate the application of the statistical tests. For adults, maximum likelihood age (MLE), based on the archaeological prior probability, was used to classify the individual into the correspondent age category (Table 17). The priors used in the age estimation were: unknown ancestry and archaeological mortality model.

Table 17: Equivalences between age ranges and age categories

MLE (years)	Age group
18 – 39.9	Young adult
40 – 59.9	Middle adult
>60	Old adult

B.2.2.2 Sex assessment

The sex assessment was only be attempted once the individual had been estimated to be over 18 years of age or adult. To this aim, the morphology of the pelvis (Phenice 1969; Krogman and İşcan 1986; Klales et al. 2012) and the morphology of the skull (Krogman and İşcan 1986; Walker 2008) were evaluated. If the pelvic and the skull features were not coherent in the assessment, the pelvis features were given preference as, while both areas have high accuracy rates, the function-related pelvic dimorphism possibly makes this area more reliable for sex assessment (Mays and Cox 2000: 120).

B.2.3 Evaluation of the spinal manifestations of DISH

In all the adult individuals, the spine was been evaluated and the following features observed. This section defines how the recording of the vertebra was been undertaken.

B.2.3.1 Preservation of the spine

The vertebrae that show no signs of damage (independent of their completeness) have been classified as having an *excellent* preservation (Figure 35). If the edges of the endplates or the anterior portion of the vertebrae appeared slightly damaged but the overall shape and appearance of the vertebra was still identifiable and the presence of osteophytes and level of endplate degeneration were assessable, the preservation was qualified as *good* (Figure 36). If the damage affected the vertebral body prevented the complete evaluation of the level of degeneration of the endplate or the presence of anterior excrescence, the vertebral bodies were classified as *poorly* preserved (Figure 37). Lastly, if there was a complete destruction of the vertebral bodies and thus the characteristics of the endplate and the apophyseal joints were not observable, the vertebrae were considered *not assessable*.

Figure 35: Example of excellent preservation. Individual 79 from the site of Chichester (University of Bradford) (source: author).

Figure 36: Example of good preservation. Individual 3007 from the site of Hereford Cathedral (University of Bradford) (source: author).

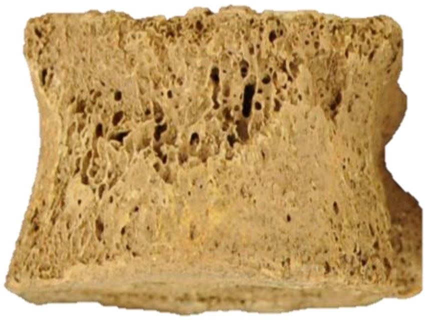


Figure 37: Example of poor preservation. Individual 1768 from the site of Hereford Cathedral (University of Bradford) (source: author).

B.2.3.2 Completeness of the vertebrae

Diffuse idiopathic skeletal hyperostosis only affects the vertebral body, thus for the purpose of determining the vertebral completeness, only the vertebral body was considered. A vertebral body will be classified as *complete* if the body was preserved in one single piece or the fragments it was broken into allowed the reconstruction of a complete anterior surface (Figure 38). Vertebrae were considered *fragmented* if a body has been broken into two or more pieces and it could not be fully reconstructed (Figure 39). In this case, the specific identification of all the vertebral fragments was attempted. In the cases where the anterior surface of the vertebral body was preserved but the central area of the body was not present – the vertebra appear as if it were a U – the anterior surface was still evaluated (Figure 40).

Figure 38: Example of complete vertebral body. Individual 3007 from the site of Hereford Cathedral (University of Bradford) (source: author).

Figure 39: Example of fragmented vertebral body. Individual 118 from the site of Kingsholm, Gloucester (University of Bradford) (source: author).

Figure 40: Example of U-shaped fragmentation as a result of central body destruction. Posterior view. Individual 123 from the site of Chichester (University of Bradford) (Source: author).

B.2.3.3 Description of the stages of DISH development in the spine

The identification of the outgrowths was done according to the results observed in the analysis of the individuals from the WM Bass Donated Skeletal Collection (see Section A.2.2.3). In short, vertebral outgrowths were classified as *isolated outgrowths* (Figure 41) when only a single vertebral outgrowth was identified or when there were more than one but these were completely unrelated. *Interlocking outgrowths* (Figure 42) were the lesions located in adjacent vertebrae that had evolved enough to be touching but no bridge had yet been formed. Finally, *ankylosed outgrowths* (Figure 43) were those located in adjacent vertebrae that have formed a complete bridge.

Figure 41: Example of isolated outgrowth in lumbar vertebra Individual 7 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Figure 42: Example of touching or interlocking outgrowths in thoracic vertebrae. Individual 1768 from the Hereford Cathedral collection (University of Bradford) (source: author).

Given the great similarity between some consecutive vertebrae, if a vertebra with an outgrowth lesion could not be positively located, the section of the spine where this vertebra possibly belonged to was assigned as *possible vertebra.*

Figure 43: Ankylosed outgrowths forming complete bridges expanding across the thoracic and the lumbar vertebrae. Note the interlocking outgrowth between T9 and T10. Individual 14 from the WM Bass Donated Skeletal Collection (University of Tennessee) (source: author).

Derived from the observations from Part A, a new diagnostic criteria was defined which included only the spinal manifestations and took into account the early stages of DISH development (Table 18).

Table 18: Diagnostic criteria for DISH

Stage		Description
Early DISH	1	**Isolated outgrowths** can be found at the thoracic spine (can also be seen at the lumbar level). The outgrowth can be accompanied by slight disc degeneration or discarthrosis but is most often unaccompanied. In some cases, a similar outgrowth can be found at adjacent vertebrae; in this case, the adjacent outgrowths are not touching or interlocking.
	2	**Touching or interlocking outgrowths** in adjacent thoracic and/or lumbar vertebrae. The outgrowths can be accompanied by slight disc degeneration or discarthosis but are usually unaccompanied
DISH	3	Presence **one complete osseous** bridge between two adjacent vertebrae. The apophyseal joints are not affected and the intervertebral disc space is retained. In very rare cases the endplates can show disc degeneration.
	4	**More than two vertebrae involved** in the ankylosis. The apophyseal joints are not affected and the intervertebral disc space is retained. In very rare cases the endplate of the affected vertebrae show disc degeneration.

To differentiate the lesions associated with DISH from the characteristic horizontal osteophytes associated to discarthrosis and the vertical syndesmophytes associated to ankylosing spondylitis, the features described and discussed in Section A.4.3 had to be respected. That is: the height of the intervertebral disc space as well as the apophyseal and sacroiliac joint spaces had to be maintained. The lesions needed to be located at the anterior surface had to emerge from the central section of the vertebral body, have a vertical orientation and be clearly overhanging at the level of the intervertebral disc space. Where observable, these lesions also had to have a cortical external layer and infilled with well organised trabecular bone.

Finally, to further investigate the co-morbidity between DISH and discarthrosis and test the hypothesis from the Bass Collection that both conditions could be found in the same spine (see Section A.4.5), the presence of discarthrosis was recorded in all spines that fulfilled the inclusion criteria.

B.2.4 Evaluation of the extra-spinal manifestations of DISH

Part A showed that the relationship between spinal and extra-spinal manifestations are not straight forward and pointed at a high degree of inter-individual variability in the presence of peripheral enthesophytes associated to DISH. The association between these two features will then further explored in the English and Catalan archaeological human remains. Individuals with and without DISH will be evaluated, it is expected that if the extra-spinal manifestations (ESM) are associated to the spinal lesions, the sub-sample of individuals with DISH would show higher prevalence of ESM compared to the sub-sample of individuals without DISH. It is also expected that, if this relationship is true, the extra-spinal enthesophytes observed in individuals with DISH would be bigger than those observed in individuals without DISH.

In keeping with the method used in Part A, the entheses evaluated in this section were: olecranon process (*M. triceps brachii* tendon entheses), superior patella (*M. quadriceps femoris* tendon entheses) and calcaneal tuberosity (*M. triceps sureau* or Achilles tendon entheses). All the entheseal changes were recorded with the aim to evaluate the symmetry and size of the enthesopathies in individuals with DISH and individuals without DISH. However, as ever with the study of archaeological human remains, presence and preservation need to be taken into account since they can bias the analysis of symmetry as well as the measurement of the enthesopathy.

The enthesopathies were measured vertically from the base to its most distal point using a digital callipers and the size of the lesion rounded to the nearest 0.1mm (see Figure 13 in Section A.2.3).

B.2.5 Identification of nutrition-related conditions in adult remains

As has been mentioned in section A.1.3, diffuse idiopathic skeletal hyperostosis has, recurrently, been linked to nutrition-related conditions and metabolic imbalances. To investigate this relationship, a palaeopathological analysis was performed to all the individuals who fulfilled the spinal inclusion criteria (see section B.2.2.1) making special emphasis on the nutrition-related conditions, namely: gout, carious lesions and periodontal disease, scurvy, residual rickets and osteomalacia and enamel hypoplasia. The presence of osteoarthritis was also recorded as it has been associated to obesity (Messier 2008; King et al. 2013).

B.2.5.1 Gout

Gout is an erosive inflammatory arthropathy related to a disturbance in the purine cycle which has traditionally been related to rich diet however it does have a crucial genetic component. The failure in the clearing of the sodium urate results in the accumulation and deposition of urate crystals in soft tissues, para-articular connective tissues and marrow bone forming granulomatous masses. The accumulation of crystals within the tissues activates an inflammatory reaction resulting in the formation of well-delimited crystal-filled nodules called tophi which will leave para-articular pressure erosion lesions with a scooped-out appearance and commonly an overhanging bony projection (Figure 44) (Ortner 2003: 583-584).

Figure 44: Scooped-out lesions with overhanging margins in the right and left metatarsals suggestive of gout. Individual 727 from the Roman Catalan site of Santa Caterina (source: author)**.**

These lesions are usually located at the first metatarso-phalangeal joint, though other joints (for example the knee or the hip) can be affected, lower extremities are more commonly affected than the upper ones (Ortner 2003: 583). Clinically, gouty lesions can also be found in the knee and the wrist (Aufderheide et al. 2011). When the lesions are x-rayed, they show a well-demarcated sclerotic margin (Rothschild and Heathcote 1995). Finally, Littlejohn and Hall (1982) found that from their sample of 99 individuals with gout, 43% also had radiological changes indicative of DISH.

B.2.5.2 Carious lesions

Carious lesions are funnel-shaped cavities that penetrate the enamel and reach the dentine and, in advanced stages, can cause the destruction of the entire crown and even the root of the tooth. These cavities are the result of the activity of cariogenic bacteria whose production of acid will cause the local demineralisation of the enamel. Carious lesions can be found at the occlusal and the interproximal dental surfaces as well as at the dental root however the location of the lesion will depend on the type of diet and the bacteria involved in it. The advance of the infection from an untreated carious lesions can reach the bone, creating an abscess and resulting the destruction of the alveolar bone (Ortner 2003: 590).

B.2.5.3 Osteoarthritis

Osteoarthritis (OA) is a slowly progressive condition highly prevalent in the modern population. In archaeological human remains, the presence of eburnation is considered to be the pathognomonic sign of osteoarthritis however in absence of eburnation, OA can also be diagnosed by at least two of the following features: contour changes of the joint, presence of marginal osteophytes and presence of subchondral cysts (Rogers and Waldron 1995: 44; Ortner 2003: 546). Although the aetiology is still poorly understood, primary OA seems to be related to age and to joint use. It is possible that some kind of hereditary predisposition to OA also exists. Secondary OA develops earlier in life and it is related to a primary pathological condition, such as trauma (Ortner 2003: 547). Finally it is worth noting that, clinically, obesity has been shown to contribute to the progression of OA, mainly to the knee (Messier 2008; King et al. 2013).

B.2.5.4 Vitamin C deficiency: Scurvy

Scurvy is a condition related to vitamin C deficiency and its symptoms are related to the age of the individual as well as to the severity and length of the deficiency. Most of the scorbutic signs observed in archaeological human remains are related to the role this vitamin has in the maintenance of collagen formation (Brickley and Ives, 2008: 48).

Scorbutic lesions in juvenile individuals are more evident than in adults due to the rapid bone growth in this individuals. Briefly, as juveniles were not recorded, these are caused by the avitaminosis as well as by the trauma to the weakened bones and blood vessels (Ortner 2003: 15). The most common signs are abnormal porous and hypertrofic lesions at the cortical bone of sphenoid, mandible, maxilla, orbits, scapula (Figure 45) and new bone formation at the end of long bones, costochondral junction and structural defects (Ortner and Ericksen 1998).

Figure 45: Porosity and new bone formation at the supraspinous scapular fossa (left) and the internal surface of the left mandibular ramus (right) in two subadult individuals from the Roman site of Tarraco. Individuals T2-22B-99-UF4 and TVB-2000-1048 respectively (source: author).

Scurvy in adult individuals can be easily mistaken for infectious, traumatic or inflammatory conditions. It is important to notice that scorbutic lesions are not pathognomonic, thus the skeletal distribution must be taken into account in order to issue a diagnosis of scurvy. Nevertheless, in adults, porotic lesions in the greater wings of the sphenoid, porous new bone formation at the posterior surface of the maxillae and at the medial surface of the mandibular rami, and abnormal porosity and plaques of porous new bone formation at the alveolar bone and palatine are regarded lesions that allow a definite diagnosis of scurvy (Geber and Murphy 2012). Furthermore, new bone formation in the orbits and in the epiphyses of long bones (particularly of radii, ulnae, coxae, tibiae, fibulae), active porous lesions in infraorbital foramina and transverse fractures at the osteocartilaginous joints of the ribs, ante-mortem tooth loss of single rooted teeth, vertebral osteopenia and bi-concave compression of the vertebral endplates have been described as signs of scurvy in adults (Ortner 2003: 387; Brickley and Ives 2008: 55; Geber and Murphy 2012). Maat (2004) indicated that, in weight-bearing bones, the black stains suggestive of haematomas were usually bilateral but could also be found unilaterally at the muscle entheses of the non-bearing bones. Also, Cybulski (1988) suggested that the marked deposition of fine textured bone deposited on the long bones might represent the calcification of subperiosteal haemorrhages and thus be indicative of scurvy.

B.2.5.5 Vitamin D deficiency: Residual rickets and osteomalacia

Rickets and osteomalacia are the result of inadequate or impaired mineralisation of bone usually caused by vitamin D deficiency. When this impairment happens during childhood, the condition is referred as rickets and when it happens when the skeleton has stopped growing, osteomalacia (Whyte and Thakker 2009).

Vitamin D deficiency in children prevents the deposition of calcium in the developing cartilage and thus the correct mineralisation of bone. This poor mineralisation of endochondral bone combined with the mechanical forces acting on the weakened bone can deform the cartilage which, if small amounts of vitamin D are available, will ossify retaining the typical deformity observed in rickets, the bending deformities and metaphyseal swelling of bones (Brickley and Ives 2008: 90, 98). Rachitic bones are characteristically osteoporotic with thin cortex and sparse cancellous bone, commonly accompanied with periosteal deposition of osteoid and flaring of metaphyses (Ortner 2003: 394). Coxa vara, flattening of the bone beneath the femoral head, medial tilting of the distal epiphysis of the tibia, and porosity of the metaphyseal surface have also been described in rickets (Mays et al. 2006). Active rickets is also characterised by the increased porosity and thickening of the cranial bones, mainly at the parietal and the occipital squama. When the intake of vitamin D or the exposure to sunlight increase, the individual can overcome rickets. The bone bending and the epiphyseal flaring deformities become then permanent and usually show remodelling changes which are referred as healed or residual rickets (Figure 46) (Brickley and Ives 2008: 91; Pinhasi and Mays 2008: 218).

Figure 46: Possible case of healed rickets. Individual T2-24-06-UF01-A from the Roman Catalan site of Tarraco (source: author).

Osteomalacia is the lack of proper bone mineralisation due to vitamin D deficiency in adulthood. The most typical macroscopic manifestations of osteomalacia in archaeological human remains are the pseudofractures. These symmetrical lesions are accumulations of unmineralised osteoid in specific skeletal locations possibly related to arterial pressure to or to traumatism on the weakened bone. In either case, the initial insult will cause the formation of a callus which, due to the lack of vitamin D, will be highly disorganised and susceptible of a secondary fracture. Thus pseudofractures are possibly related unhealed stress fractures. The presence of these pseudofractures in the ribs and on the spinous process of the scapula are regarded as highly indicative of osteomalacia although these can also be observed in other areas like the superior and inferior pubic rami, the medial femoral neck and medial sub-trochanteric regions and the pelvis (Brickley et al. 2005; Brickley and Ives 2008: 118-119; Ives and Brickley 2014). Other features such as vertebral collapse, cupping of the endplates and reduction of the vertebral trabecular bone, rib deformation accompanied by protrusion of the sternum and deformation of the pelvis and long bone bending deformities have also been described in cases of osteomalacia (Ortner 2003; Ives and Brickley 2014).

B.2.5.6 Enamel hypoplasia

Linear enamel hypoplasia (LEH) is a linear or pitted enamel defects arranged in a circumferential fashion around the enamel and used as a non-specific marker of systemic stress, such as malnutrition, disease or fever, during early life while teeth are forming (Katzenberg and Saunders 2008; Ogden 2008: 284). While linear and pitted enamel defects are the most commonly observed, cuspal enamel hypoplasia (CEH) is a more extensive type of enamel defect affecting deciduous or permanent molars. CEH is characterised by the combination of pitted and plane defects combined with the disruption of the cusp pattern and the formation of small cusps thus this defect seems to develop at the onset of the tooth formation (Ogden et al. 2007). The authors suggested that these lesions could indicate a systemic disorder happening the first 2 years of life.

B.2.5.7 Working hypotheses and expected co-morbidities

As it has been extensively described in Section A.1.3, the consensus is that there is some kind of relationship between DISH, highly caloric diets and metabolic derangements. In this sense, the working hypotheses are that the prevalence of gout will be higher in the sub-sample of individuals with DISH because both conditions have been associated with age and rich diet. Similarly, it is expected that the prevalence of carious lesions will be higher in the sub-sample of individuals with DISH. Finally, it would not be unexpected to obtain a direct correlation between OA and DISH since both conditions also are positively related to age and to obesity.

Because scurvy and osteomalacia are associated with vitamin C and D, respectively, it is expected that the prevalence of these conditions will be lower in individuals with DISH than in individuals without DISH.

Residual rickets and enamel hypoplasia are, respectively, the reflection of a vitamin D deficiency and metabolic stress during childhood development therefore, theoretically, there should not be any relationship between these conditions and DISH. Thus it is expected that the prevalence of residual rickets and of enamel hypoplasia will be similar in the subsamples of individuals with and without DISH. While it has been suggested that early obesity, at 20-30 years of age, might be related to the development of DISH later in time (see section A.1.3.1), there is no reason to believe that rickets, whose peak of incidence in modern times is between 3 and 18 months, or linear enamel defects which reflect the 10 to 11 years of life (Brickley and Ives 2008: 91; Pinhasi and Mays 2008: 284), could be somehow related to DISH.

B.2.6 Stable isotope analysis

Carbon isotope can be used to differentiate between diets based on C_3 or C_4 plants as well as terrestrial *versus* marine diets as C_4 plants and marine-based diets show higher carbon value compared to the C_3 plants and terrestrial-based diets (Schwarcz and Schoeninger 1991; Ambrose 1993; Pollard and Wilson 2001). In contrast, nitrogen values can help to position the individual within the trophic chain and to identify the source of the protein as marine resources show higher nitrogen values compared to the terrestrial sources (Schwarcz and Schoeninger 1991; Hedges and Reynard 2007; O'Connell et al. 2012; Huelsemann et al. 2013). However it should also be noted that many ranges to sometimes overlap and that intermediate marine-terrestrial isotope values (e.g. freshwater resources) could easily be masked by a stronger terrestrial or marine signature (Schoeninger et al. 1983; Dufour et al 1999). Therefore to attempt a dietary reconstruction, a geographically and temporally relevant animal baseline should be used to contextualise the results.

Furthermore, other factors that can influence the isotope fractionation should be taken into account. For example, while there is no age or sex-dependant carbon or nitrogen physiological difference (Schwarcz and Schoeninger 1991), the variation of human nitrogen isotopic values under different conditions such as pregnancy, growth, illness, physiological stress has been recurrently reported (Katzenberg and Lovell 1999; Fuller et al. 2004; Fuller et al. 2006; Waters-Rist and Katzenberg 2010; Beaumont et al. 2015; D'Ortenzio et al. 2015). High temperatures, altitude and aridity (Ambrose 1991, 1993; Schwarcz and Schoeninger 1991, Richards and van Klinken 1997) can also affect the carbon and nitrogen isotopic fractionation. Finally, agricultural techniques such as manuring can directly affect the nitrogen isotope values, which, in its turn will affect the herbivores and human's nitrogen values thus confusing the interpretation of the type of diet proposed for a specific population (Bol et al. 2005; Kanstrup et al. 2005; Huelsemann et al. 2013). For a full review of the collagen characteristics, the carbon and nitrogen metabolism and a discussion of the stable isotope analysis, its potential and its limitations, see Appendix 6.

As DISH has been recurrently associated to a rich diet, it is possible that individuals with DISH show a different isotopic signature compared to those individuals without DISH. It is hypothesised that the individuals with DISH will show higher $\delta^{13}C$ and $\delta^{15}N$ values as a result of a higher intake of fatty fish and meat. It is also possible that the individuals from Catalonia show higher $\delta^{13}C$ values as a result of the direct or indirect intake of C4 plants (e.g. *spartina* and millet) which are authocthonous to the area (Alonso Martínez 2000; Tafuri et al. 2009; López-Costas and Müldner 2016).

B.2.6.1 Sample selection for stable isotope analysis

B.2.6.1.2 Human samples

To analyse the relationship between DISH and diet, carbon and nitrogen isotopes from bone collagen have been analysed. For the analysis, only rib samples were selected. 33 samples were selected from individuals buried at the Romano-British site of Baldock, in Hertfordshire (see Section B.3.2.2.1 for description of the site).

The characteristics of the individuals, their DISH status as well as the identified co-morbidities and the original weight of the sample are shown in table 19. The colour code used in this table refers to the severity of the spinal manifestations of DISH – the darker the shade, the more advanced the development of DISH.

Table 19: Individuals selected from the Romano-British site of Baldock

Ind. ID	Sex	Age (95%)	DISH	Co-morbidities	Sample weight
Bal F18 L10	M	33.8 (26.3 – 44)	N	-	684.8
Bal F92	M	79.7 (60.6 – 92.2)	4	H. rickets (?)	623.8
Bal F466	M	39.4 (27.1 – 73.5)	N	H. rickets[1] (?), gout, LEH[2]	576.5
Bal F475 L2	M	73.2 (50.7 – 88.1)	N	LEH, CL[3]	609.9
Bal F610 L1	F	26.7 (20.7 – 35.5)	N	-	923.8
Bal F644	F	74.5 (38.3 – 90.3)	N	-	664.2
Bal 883	M	31.1 (25.1 – 39.1)	N	CL, H. rickets (?)	674.5
Bal 1022	F	63.5 (33.9 – 84)	N	-	559.6
Bal 1028	F	32.3 (22.6 – 50.0)	N	-	639.7
Bal 1040	F	61.8 (32.6 – 86.6)	N	LEH, CL	592.8
Bal 1049	M	75.6 (34.6 – 91.4)	2	-	536.8
Bal 1072	M	47.0 (32.5 – 75.1)	1	CL, LEH	1073.9
Bal 1077	F	75.1 (54.1 – 89.2)	N	H. rickets (?)	718.1
Bal 1090	M	48.6 (33.5 – 74.2)	N	-	891.1
Bal 1107	F	71.0 (45.8 – 87.4)	N	-	1020.5
Bal 1122	F	80.0 (61.8 – 92.4)	4	-	604.1
Bal 1174	M	28.9 (28.9 – 84.4)	N	-	913.9
Bal 1203	M	72.5 (47.4 – 87.9)	N	-	1314.7
Bal 1237	M	75.9 (49.5 – 90.6)	N	Gout (?), CL	622.4
Bal 1263	M?	A	N	-	554.7
Bal 1281	F	73.1 (49.4 – 88.6)	N	H. rickets (?), CL	1309.0
Bal 1319	F	68.6 (44.8 – 85)	N	CL	637,3
Bal 1320	M	41.4 (29 – 67.8)	N	CL	1844.0
Bal 1342	U	64.1 (33.1 – 84.9)	N	-	1867.0
Bal 1372	M	70.6 (44.5 – 87.1)	N	-	633.9
Bal 1374	M	74.3 (29.1 – 90.8)	2	-	905.1
Bal 1391	F	62.5 (27.3 – 85.5)	N	-	617.3
Bal 1446	F	39.2 (27.1 – 61.2)	N	-	659.2
Bal 1447	F	38.3 (21.4 – 71.8)	N	LEH, CL	693.6
Bal 1480	M	29.9 (21.5 – 45.6)	N	CL	645.3
Bal 2225	M	45.8 (32 – 72.5)	2	CL	834.4
Bal 2601	F?	82.1 (65.2 – 93.6)	N	LEH, CL	1738.0
Bal 3644	M	37.5 (28.2 – 54)	N	-	608.5

[1]H. Rickets: healed rickets; [2]LEH: liniar enamel hypoplasia; [3]CL: carious lesions. (?) probable diagnosis

41 samples were selected from individuals buried at the Catalan Roman site of Santa Caterina (see Section B.3.2.3.1 for description of the site). The characteristics of the individuals, their DISH status as well as the identified co-morbidities and the original weight of the sample are shown in table 20. The colour code used in this table refers to the severity of the spinal manifestations of DISH – the darker the shade, the more advanced the development of the condition.

Table 20: Individuals selected from the Catalan Roman site of Santa Caterina

Site code	Ind. ID	Sex	MLE Age (95%)	DISH	Co-morbidities	Sample weight (mg)
010/04	T3	M	38.1 (21.0 – 81.9)	N	H. rickets	755.0
010/04	T14	M	76.6 (40.3 – 91.5)	N	-	665.7
010/04	T15	M	72.4 (40.7 – 89.1)	N	LEH	747.4
010/04	T18	M?	70.8 (21.9 – 89.3)	N	H. rickets (?)	1000.2
002/00	706	M	47.6 (24.0 – 83.2)	N	LEH	962.6
002/00	707	F	54.1 (34.0 – 78.4)	N	CL, LEH	764.4
002/00	708	F?	26.7 (26.7 – 45.3)	N	-	669.9
002/00	709	M	76.0 (52.5 – 90.3)	N	CL, LEH, AS (?)	714.7
002/00	710	M	15.0 (15.0 – 21.4)	N	LEH, pos. rickets, Leprosy	896.3
002/00	719	M	71.7 (71.7 – 90.4)	N	Early gout, CL	1071.6
002/00	721	F?	18.3 (18.3 – 31.4)	N	Scurvy, gout (?)	726.2
002/00	725	F	66.3 (40.6 – 85.6)	N	H. rickets, LEH, gout (?), leprosy (?)	942.6
002/00	727	M	75.6 (54.5 – 89.6)	1	H. rickets, gout	956.1
002/00	729	F	74.6 (47.9 – 89.9)	N	CL, LEH	641.6
002/00	731	M	46.5 (32.1 – 74.4)	N	CL, LEH	727.2
002/00	732	F	32.7 (24.5 – 46.3)	N	-	814.3
002/00	733	F	35.4 (25.8 – 51.5)	N	-	619.6
001/01	748	F?	77.3 (44.6 – 92.0)	N	Rickets	579.2
001/01	754	M	77.0 (21.6 – 110)	1	CL	895.8
001/01	755	F	71.4 (47.5 – 87.7)	N	CL	706.5
001/01	756	M	72.8 (44.9 – 88.9)	2	LEH	656.3
001/01	758	F	15.0 (15.0 – 30.1)	N	LEH	666.2
072/86	A1.124	M	75.2 (49.1 – 90.1)	N	-	990.0
072/86	B1.93	F	76.8 (46.5 – 91.3)	N	CL	642.2
072/86	B1.119	M	35.0 (27.6 – 46.2)	N	LEH, CL,	833.4
072/86	B1.123	F	66.0 (42.8 – 83.8)	N	H. rickets (?), CL	741.2
072/86	B1.148	M	50.5 (24.6 – 84.8)	N	H. rickets	828.7
072/86	B2.50	M	63.3 (31 – 86.7)	N	LEH	698.3
072/86	B2.57	F	58.3 (29.9 – 83.2)	N	-	657.3

072/86	B2.62	M	39.2 (30.3 – 54.9)	N	CL	629.0
072/86	B3.21	F	60.8 (37.5 – 81.1)	N	LEH, CL	841.0
072/86	B3.59	M	37.3 (27.6 – 54.1)	N	-	875.0
072/86	B3.67	F	34.3 (25.2 – 50.3)	N	LEH, CL	1037.6
072/86	B3.87	M	30.5 (25.6 – 37.0)	N	LEH	764.7
018/01	T15	M	35.2 (23.3 – 63.1)	N	CL	6225
018/01	T25	M	36.6 (27.8 – 51.4)	N	Gout, CL	960.3
018/01	T29	F	42.1 (28.7 – 64.3)	N	LEH	1062.1
201/05	UF1	F	51.2 (32.8 – 77.3)	N	H. rickets (?), LEH	659.5
201/05	UF19	F	50.8 (25.3 – 81.3)	N	CL	764.9
201/05	UF28	F	34.9 (25.6 – 50.8)	N	H. rickets (?)	807.4
162/06	UF06	M	35.1 (27.9 – 45.7)	N	CL	1178.2

[1]H. Rickets: healed rickets; [2]LEH: liniar enamel hypoplasia; [3]CL: carious lesions. (?) probable diagnosis

B.2.6.2.1 Animal samples

Seven animal samples contemporaneus to the human remains from Santa Caterina and found at the same cemetery and six animal samples, three of goat/sheep and three of cattle were also selected from animal remains found in the grave infills from Baldock. The details of each sample are shown in table 21.

Table 21: Animal samples used as isotopic reference

Site	Code	Animal	Sample weight
Santa Caterina	018-01-450	Cattle	703.3
	018-01-456	Pig	527.9
	137-05-81.1	Sheep/goat	593.7
	137-05-81.2	Sheep/goat SA	581.5
	137-05-100	Goat	598.1
	137-05-123	Cattle	595.4
	137-05-125	Dig	719.2
Baldock	BAL1480-1	Sheep/goat	650.3
	BAL1480-2	Sheep/goat	579.7
	BAL1480-3	Sheep/goat	608.4
	BAL2322-1	Cattle	760.3
	BAL1480-2	Cattle	801.7
	BAL1480-3	Cattle	617.9

B.2.6.2 Stable isotope analysis method

Collagen was prepared using the modified Longin method (O'Connell and Hedges 1999; Brown et al. 2006). Approximately 500 to 700mg of bone was sampled, submerged in 0.5 M hydrochloric acid and stored in the fridge for demineralisation. The acid in the samples was changed every two to three days until the demineralisation was complete, this process took between three and six weeks. Samples were then rinsed with de-ionized water and placed in sealed tubes with pH3 hydrochloric acid solution at 70ºC for 48 hours to allow the collagen fibrils to go into solution. The bone was then filtered with easyfilters and each sample was then split into two subsamples. The samples were then freezed at -36ºC for at least a day and freeze-dried for 48 hours to remove any remaining water. The dried cotton-like collagen was weighed to calculate the yield of collagen and between 0.3 and 0.6 mg of collagen were introduced in a tin capsule. The samples were then combusted in a Thermo Flash EA 1112 and the separated N^2 and CO_2 was introduced to a Delta plus XL via a Conflo III interface.

The results are expressed using the delta (δ) notation in parts per thousand (per mil; ‰) relative to the international standards: the marine limestone (VPDB) for carbon and Ambient Inhalable Reservoir (AIR) for nitrogen isotope ratios. When calibrated against international and laboratory standards, the analytical error was determined at ±0.2% (1 standard deviation) or better (Beaumont et al. 2013).

B.2.7 Statistical analysis

To evaluate the reliability and significance of the analysis, statistical tests were applied using SPSS version 24 software. The tests applied to the sample size were the following:

- Independent sample Kruskal-Wallis test: to compare the demographic profiles of the different populations and to assess the relationship between age and DISH status.
- Chi-square Test: to compare the sex ratios between the different populations and to explore the relationship between the prevalence of DISH and the different populations depending on the time period and on the geographic location and to evaluate the correlation between the type of diet and the DISH status.
- Fisher's Exact Test: to study the relationship between sex and the DISH status where cells have low counts.
- Spearman's Rho Test: to study the correlation between the age categories and the stage of development of the spinal and the extra-spinal manifestations and to evaluate the correlation between stage of development of the spinal and the extra-spinal manifestations. To increase the robusticity of the analysis, as both the vertebral ankylosis as well as the extra-spinal enthesopathies can only be progressive, the Spearman's rho test has been considered single-tailed.

For all tests, the significance value was set to 0.01 to reduce the risk of Type II errors resulting from the high number of test performed.

The following considerations have been taken when applying the statistical tests to the sample:

a. The individuals that in the sex assessment were qualified as *undetermined* or *unobservable* were not taken into account in the statistical evaluation of the relationship between sex and DISH.

b. Individuals aged as *adult* were not taken into account in the statistical evaluation of the relationship between age and DISH.

B.3 COMPARISON OF REGIONS: ENGLAND AND CATALONIA

In this chapter, an initial overview of the English and Catalan chronologies will be shown and the rationale behind the choice of the archaeological sites included in this project explained. This chapter also contains brief summaries of the historical and archaeological contexts of the sites selected and its population.

The regions of England and Catalonia were chosen because their respective diet and life-style might have been different through time. Thus they offered the possibility of explore the relationship between these and the development and prevalence of DISH.

B.3.1 Comparison of English and Catalan chronologies

While the same periods of Roman, early medieval or Anglo-Saxon, late medieval and post-medieval/early modern are shared with most of the western European region, the transitions between periods might be not correspondent between these different regions. To have a better idea of how the time periods between English and Catalonia compare, here, a simplified version of both chronologies with their corresponding years is presented (Table 22).

Because of the different durations and size of the cemeteries, it can be complicated to find directly comparable sites. Thus to address this problem, it has been the aim to pair English and Catalan sites that were in use during the same centuries. If a cemetery’s life spanned two time periods, the burials have been classified to each period represented using the archaeological reports or talking directly to the archaeologists who directed the excavation.

Table 22: Comparison of the English and Catalan historical chronologies

	England	Catalonia	
... 200 BC	**Iron age** 800 BC – 43 AD	**Iberian Period** ±750 BC - ± 200 BC	
100 BC		**Roman Period** ± 200 BC – 475 AD	
0	**Romano British** 43 AD – 410 AD		
100 AD			
200 AD			
300 AD			
400 AD	**Anglo Saxon or early medieval period** 410 AD – 1066 AD	**Visigoth Period** 475 AD – 720 AD	Early medieval 475 AD – 1000 AD
500 AD			
600 AD			
700 AD		**Muslim Period in Catalonia** 720 AD – 785 to 810 AD	
800 AD		**Catalan Counts** 785 AD – 1000 AD	
900 AD			
1000AD	**(Late) medieval period** 1066 AD – 1485 AD	**Late medieval Period** 1000 AD – 1453 AD	
1100 AD			
1200 AD			
1300 AD			
1400 AD	**Post-medieval Period** 1485 AD – 1707 AD	**Post-medieval period** 1453 AD – 1789 AD	
1500 AD			
1600 AD			
1700 AD		**Contemporary Era** 1789 AD – now	
1800 AD	**19th Century England**		

B.3.2 Selection of the archaeological sites

In the following section, the strict inclusion criteria for the sites is explained and justified. Afterwards, the contextual information for each of the selected sites in England and Catalonia is summarised with emphasis set on the type of settlement as well as any event that could have affected the life of its inhabitants.

B.3.2.1 Inclusion criteria for the sites

All the sites included in this project had to fulfil three criteria:

1. Size: to be able to perform statistical analysis, it was decided that all sites had to have at least **100 individuals** in total, if possible more. This threshold was established because during the previous pilot study (Castells-Navarro 2013) it became clear that, due to preservation problems, a high percentage of the adults would not fulfil the inclusion criteria of at least three well-preserved lower thoracic vertebrae present for the identification of DISH (see section B.2.2). In some cases where the final number of individuals that fulfilled the spinal criteria was very low, several contemporaneous sites have been combined (Table 23 and 24 show the original number of individuals reported and final sample size for each site).

2. Type of site: while the aetiology of DISH still remains unclear, it is well known that its prevalence in a society or a community is influenced by the life style of the inhabitants. Julkunen (1971) argued that the different prevalence of DISH observed in living in rural and urban populations could be related to the life style of each community. Furthermore while it is not clear whether the men living monastic community did have significant higher prevalence (Waldron 1985; Rogers and Waldron 2001; Mays 2006; Verlaan et al. 2007),

it is clear that these communities do not represent the entire society as they would have followed distinct dietary patterns as a result of the observance of the Christian food regulations. Therefore to avoid inherent biases in the sample, all the sites selected had to be classified as **nucleated centres and lay cemeteries**.

3. Chronology: because one of the aims of the project is to evaluate the progression of the prevalence of DISH through time, it was paramount that the sites selected had a **clear chronology**. If the stratigraphy suggested that more than one period was represented in the site, it was also deemed necessary that, at the time of excavation, enough information about the burial type was collected by the archaeologists to be able to allocate each burial to a chronological period.

4. Preservation: for the site to be selected, its report had to have a mention on the preservation state of the individuals and only sites where the preservation of the human remains was described as generally excellent/good were selected. In cases where the real preservation was found to be not good enough, comparable sites were combined to fulfil criteria 1 (sample size of over a 100 individuals).

B.3.2.2 Selected sites from England

Table 23 shows the number of individuals reported and the final sample size for each English population analysed in this project. The value in brackets in the ‘adult individuals’ column is the percentage of adults in the total site and the value in brackets in the ‘final sample size’ is the percentage of adult individuals with evaluable spine in each site. The final sample size is of 281. Figure 47 shows the location of the English sites used in this project.

Table 23: Summary of original and final sample sizes for the selected English sites

Period	Site	Total sample size	Adult individuals[a]	Final sample size
Romano – British	Baldock	94	80 (85.1)	36 (45.0)
	Kingsholm	50	41 (82.0)	14 (31.4)
	Gambier Parry Lodge	125		24 (19.2)[b]
Anglo-Saxon	Raunds	357	191 (53.5)	116 (60.7)
Late medieval	Fishergate House	244	131 (53.7)	64 (48.9)
Post-medieval	Wolverhampton	152	92 (60.5)	27 (29.3)

[a] When data was available. [b] Percentage of adult individuals with evaluable spine in the total sample.

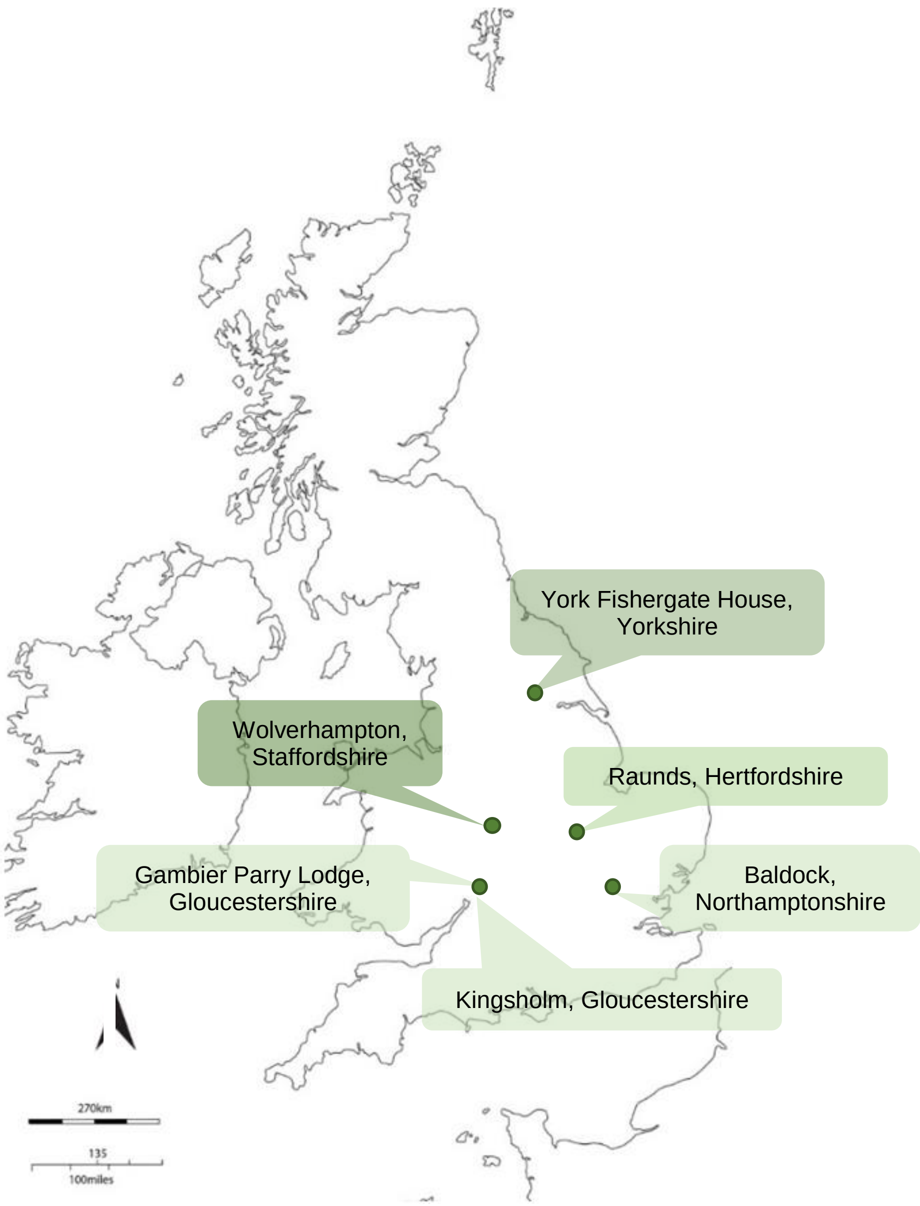


Figure 47: Location of the selected sites for England

B.3.2.2.1 Romano-British sites: Baldock, Gambier Parry Lodge and Kingsholm

<u>Baldock</u>

The Romano-British settlement of Baldock, located in North Hertforshire, was discovered in 1925 and excavated in several campaigns between then and 1994 (Burleigh et al. 2010: 9). The excavations revealed that Baldock, in the Chilterns, emerged as an important *oppidum* in the early first century BC during the late Iron

Age, from which high-status burials and a demarcated burial zone can be identified (Thompson 2015). Baldock had continuous occupation until the post-Roman period when a clear decline of the settlement can be observed (Griffin et al. 2011; Thompson 2015). The site seems to have been deserted from before 600 AD and it remained deserted until the 1140s when the Knights Templar established their new town, *Baudiac.*

While sometimes classified as a “small town” Roman Baldock was a large settlement in south-east Britain located at the crossroads of Icknield Way, which runs east – west, and Stane Street which connected it to major regional centers such as Verulamium (St Albans), London and Colchester. It exhibits characteristics of Roman urban settlement such as planned layout and monumental buildings but as it does not seem to have had a fort so it is best described as ‘nucleated settlement’ or village. Its population seem to have been largely agriculturally engaged but there is also presence of small-scale light industry and crafts. Today it still retains some of the round houses typical to the pre-Roman settlement (Burleigh et al. 2010; Griffin et al. 2011).

The Late Roman burial site of BAL-1 (known as California cemetery) is located at the crossroads north-west of the settlement and dates to the period ca. 175 – 550 AD. Its more than a hundred burials date from the late to the post-Roman period and is classified as a pagan cemetery as opposed to a Christian one (Burleigh et al. 2010). Of the 94 individuals recovered from BAL-1, 80 were classified as adults and 36 individuals fulfilled the spinal inclusion criteria.

Roman Gloucester

The Romano British sites of Gambier Parry Lodge and Kingsholm are located in the modern city of Gloucester, known as *Glevum* in the Roman period. The *colonia* of *Glevum* was founded on the Severn floodplain (Dobney et al. 1999) as a legionary fortress in the late 60s (Hurst 1985; Hurst 1999). Towards the end of the first century it became a settlement for retired Roman soldiers and by the end of the second century it was a densely populated urban centre with a forum, baths and a basilica. By road, *Glevum* was well connected to the other Roman cities and its location close to the Severn Estuary and the Bristol Channel means that *Glevum* benefited from the Roman marine trade which contributed to the increase in wealth of its inhabitants (McWhirr 1981). Pollen data suggests that *Glevum* was surrounded by an open ground of possibly disturbed grassland, which is consistent with a location on gravels above the alluvium of the Severn floodplain (Dobney et al. 1999). Figure 48 shows a detail of the Gloucester area with the location of the selected sites framed in red.

Kingsholm

The Roman presence in this area commenced by the construction, in 49AD, of the military fortress at Kingsholm (Hurst 1985), located 1 km north from the *colonia of Glevum* (Hurst and Crummy 1999). Today, Kingsholm is a district of Gloucester (McWhirr 1981). From this cemetery, 50 individuals were recovered, 41 of which were adults (Roberts 1989) and 24 adults fulfilled the spinal inclusion criteria.

Figure 48: Map showing the location of the Gloucester sites (Source: Map provided to BARC by Gloucester Museum)

Gambier Parry Lodge

The location of Gambier Parry Lodge is 15km north from the City of Gloucester in the suburb of Kingsholm (Cameron and Roberts Unpublished report). The excavation discovered 125 burials and seven cremations all dated from the early 2nd to the 4th century (Garrod 1984: 50). 14 adults fulfilled the spinal inclusion criteria.

B.3.2.2.2 Anglo-Saxon site: Raunds

The archaeological site of Raunds Furnells, located north-west of the modern city of Raunds in Nene Valley, Northamptonshire, was excavated between 1977 and 1984 (Figure 47). The site of Furnells was continuously occupied from the 6th to the late 15th centuries; but already by the 7th century, the site was composed by a series of buildings within a rectangular enclosure (Figure 49) (Boddington 1996). By the late 9th or early 10th century, a small church was constructed adjacent to a manor house complex, outside an inner court. At the beginning of the 10th century, the modest first church acquired burial rights and was increased in size with the addition of a chancel to allow for a bigger congregation. Between the 11th and the mid-12th century the first church was demolished and replaced by a larger one overlaying some of the early graves (Boddington 1996).

At least 363 individuals were buried in a cemetery between the mid-10th and the mid-12th centuries (Figure 49). Analysis of relationship between burials and the church suggests that the interments started with or just after the addition of the chancel to the church and developed in zones. When this zone was full, the burials continued outside this primary zone in a more disorganised manner. Generally speaking, burials at Furnells show considerable attention to the protection of the deceased, some burials were in coffins and others had a stone cover, possibly reflecting the wide social spectrum represented in the cemetery (Boddington 1996).

Figure 49: Drawing of Raunds Furnell site in the Anglo-Norman period

(Source: Boddington 1996: 5)

Beyond the church and the graveyard, the manor and the village were well preserved. The church seems to have been privately founded and associated with the manor, it seems it could have served a community of *c.* 40 individuals which possibly included the manor and its dependants. Another option could be that this graveyards served the late Anglo-Saxon community of North Raunds or of the entire village of Raunds, however documentary sources suggest that these communities were too big to be served by this parish alone thus it is possible that more than one graveyard was being used the community of Raunds by the late Saxon period (Boddington 1996). In the late 12th century or 13th century the church was converted, with some parts rebuilt and others reused into a manorial house which eventually would become a section of a posterior manorial house

(Boddington 1996). Of the 357 individuals recovered, 191 were classified as adults and 116 fulfilled the spinal inclusion criteria.

B.3.2.2.3 Medieval English site: York, Fishergate House

The site of Fishergate House, York (Figure 47) was excavated between July 2000 and July 2002 by Field Archaeology specialists LTD. The excavation revealed continuous activity from prehistory to the 20th century (Spall and Toop 2005).

The suburb of Fishergate dated from at least the late 10th century and the construction of several now-lost churches, dedicated to St George, St Helen, St Andrew’s and All Saints, suggest an increase in population size. During the Fishergate House (2000-2002) excavation, a medieval cemetery was located within the grounds of Fishergate House, as it is outside the Gilbertine priory of St Andrew’s precinct and far from the known location of its associated cemetery, it was suggested the cemetery could be associated to one of the other medieval churches. Due to the lack of archaeological evidence, documentary sources were used to attempt to find the church this cemetery was associated with; the best candidate being St Helen’s church was in use from at least from the 11th and until the 16th century (Spall and Toop 2005).

Of the 250 burials located, 244 individuals were recovered and six were left *in situ*. The early burials show some degree of burial organisation while the later ones have more evidence of intercutting. Most of the burials are west-east aligned with some of them showing minimal deviations. Likewise, the individual layout is very uniform, the majority of the individuals are extended and supine, with the arms extended at either side, crossed over the abdomen or on the pelvis. It is possible some individuals were buried with a shroud (Spall and Toop 2005). Two individuals were buried in a coffin and four contain grave goods in the form of a copper allow ring, a copper cross mount, an iron key and a pierced scallop shell. This last one is commonly associated with the pilgrimage to Santiago de Compostela in northwest Spain (Spall and Toop 2005). Of the 131 adults, 64 fulfilled the spinal inclusion criteria.

B.3.2.2.4 Post Medieval English site: Wolverhampton

The excavations at the overflow burial ground of St Peter's College Church, Wolverhampton city centre (Figure 50) was carried out between October 2001 and January 2002 and revealed 152 human burials from the mid-19th century (Adams et al. 2007). St Peter's Church was founded by the Mercian royal family in the 7th century AD and was an important early Christian centre but the area where the overflow burial ground stands was consecrated in 1819. During the medieval and the post-medieval period, this area had been occupied by the Deanery of Wolverhampton and its grounds and gardens (Adams et al. 2007: 1).

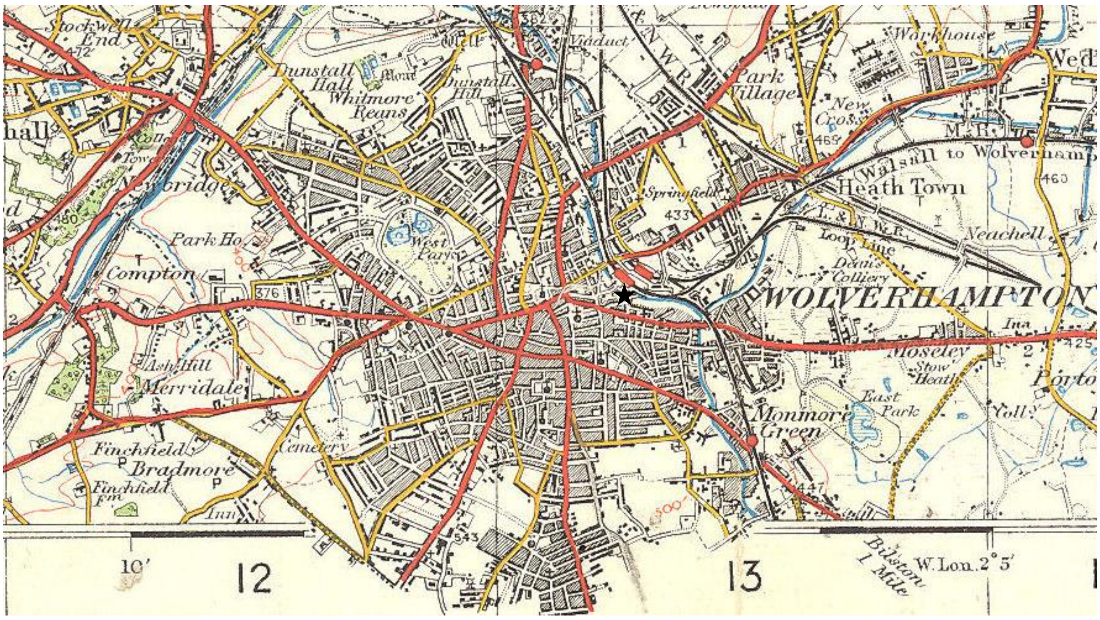


Figure 50: City of Wolverhampton in 1921 (location of St Peter's Church marked with a star) (source: Ordnance Survey Contoured Road Map of Wolverhampton, Popular Edition)

Wolverhampton emerged as an industrial centre from the 16th century, with the coal and ironstone industry. In the 17th century, the lock industry took over which was subsequently replaced by the tin-plate industry in the 18th century. By the 19th century, industrialisation, mainly centred on heavy weight manufacturing and combined with the existence of coalfields (possibly the main driver for development in the area) as well as iron ore and fire clay, attracted immigrants from the rural areas as well as from Wales and Ireland. This led to a 750% increase in the population between the beginning and the end of the century (Adams et al. 2007: 7). Because of the lack of building planning, the absence of a sewage and drains system, the overcrowding the churchyard as well as the presence of livestock in the city streets, living conditions in 19th century Wolverhampton were extremely poor. Already in 1843, these living conditions had been linked to the high mortality of the town. Short life expectancy was also linked to the endemic infectious diseases associated to the living conditions and to the poor quality of the food, which also was, in many cases, insufficient (Adams et al 2007: 7-12). Of the 152 individuals recovered, 92 were adults (Adams et al. 2007: 19) of which 27 fulfilled the spinal inclusion criteria.

B.3.2.3 Selected sites from Catalonia

Table 24 summarised the number of individuals reported and the final sample size for each Catalan population analysed in this section. The value in brackets in the 'adult individuals' column is the percentage of adults in the total site and the value in brackets in the 'final sample size' is the percentage of adult individuals with evaluable spine in each site. The final sample size is 247. Figure 51 shows the location of the Catalan sites used in this project.

Table 24: Summary of original and final sample sizes for the selected Catalan sites

Period	Site	Total sample size	Adult individuals[a]	Final sample size
Roman	Tarraco	76	52 (68.4)	23 (44.2)
	Santa Caterina	130		64 (31.5)[b]
Early medieval	Sant Esteve de Granollers	160	43 (26.9)	18 (41.9)
	Sant Pere de Terrassa	127	104 (81.9)	47 (45.2)
Late medieval	Olèrdola	178	50 (28.1)	10 (20.0)
	Sant Esteve de Canapost	198	140 (70.7)	32 (22.9)
	Sant Pere de Terrassa	36	27 (75)	14 (51.9)
	Vila-sacra	307	238 (77.5)[c]	33 (13.9)
Post-medieval	Sant Esteve de Canapost	73	60 (81.2)	6 (10.0)

[a] When data was available. [b] Percentage of adult individuals with evaluable spine in the total sample. [c] This site could not be fully analysed due to time constraints.

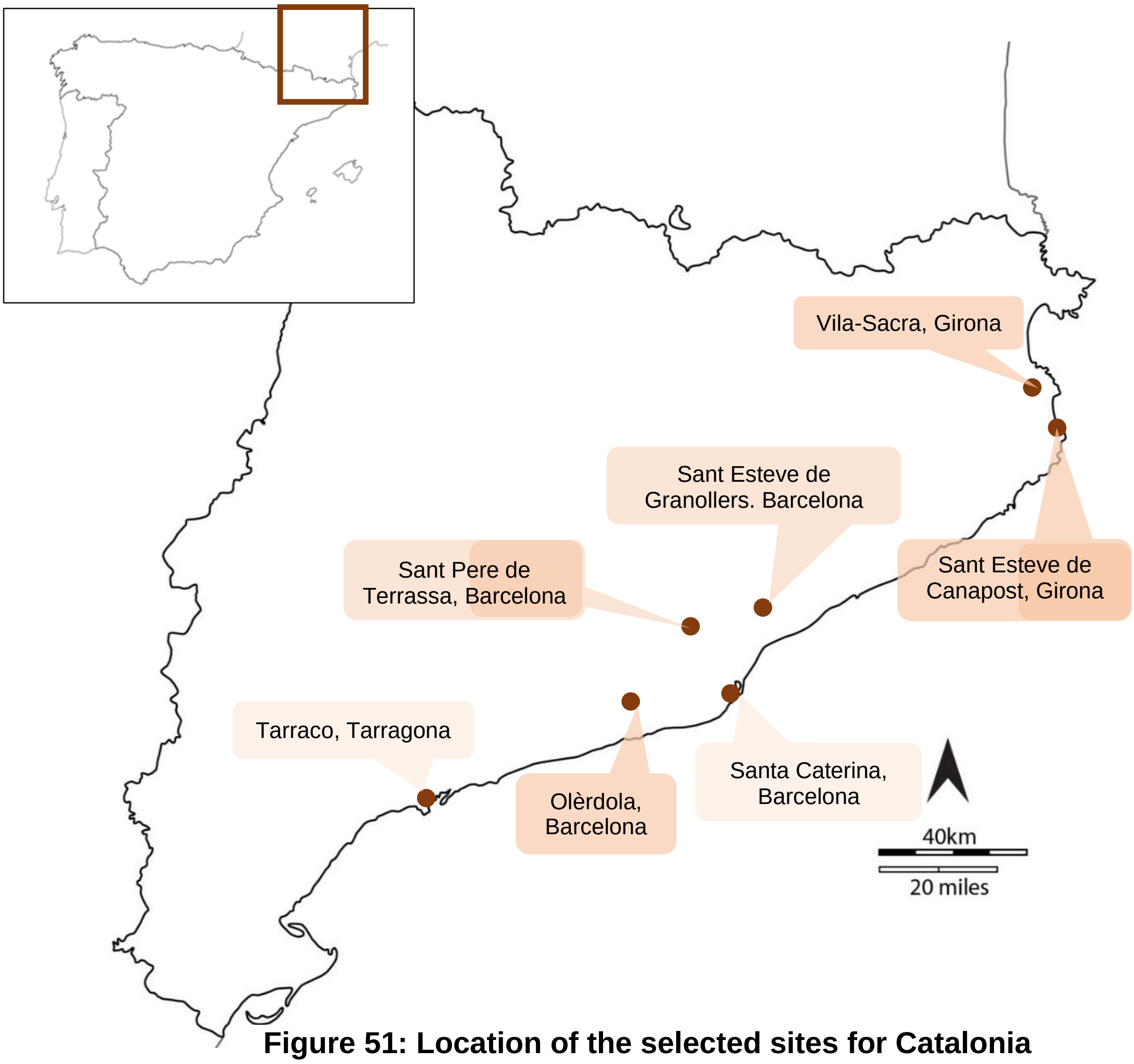


Figure 51: Location of the selected sites for Catalonia

B.3.2.3.1 Roman Catalan sites:

Mercat de Santa Caterina – Carrer Francesc Cambó, Barcelona, Catalonia

The necropolis of Santa Caterina - C. Francesc Cambó was located at the *suburbium* of the urban Roman centre of *Barcino* (Barcelona), outside the city walls but close to the roads accessing the city (Figure 52). *Colonia Iulia Augusta Fauentia Paterna Barcino* was founded in 15-5 BC on top of a hill and limited by two rivers. During the first centuries, this walled urban centre developed an important suburban activity. At some point in the 4th century, it seems the city was refortified, and in the site of the abandoned suburbium, a necropolis appeared (Aguelo i Mas et al. 2005: 16).

Figure 52: Roman Barcino (above, city walls in orange) and location of necropolis of Santa Caterina - Avinguda Francesc Cambó (shaded in orange) (A.d.B. 2018)

According to the stratigraphy, the necropolis was used between the fourth and the sixth centuries AD and had an extension of about 1,350 sqm. The cemetery was delimited and divided by a series of walls built with mortar, stone and ceramic elements. 130 individuals, all of them inhumations, have been excavated (Aguelo i Mas et al. 2005: 21). The burials are distributed in a regular manner and there is no overcrowding. Most of the individuals are buried in a SW-NE or a NW-SE orientation. All the adults were in a supine position with the arms crossed over the waist or the pelvis; the infants, in foetal position, were buried in amphorae (Aguelo i Mas et al. 2001).

The cemetery contains a wide variety of funerary styles: single burials in amphora, in coffins, in *tegulae* with a double slope or a squared section, and funerary buildings, possibly representing social or economic differences within this Roman community. The cemetery itself was well organised according to the location and typology of the tombs; for example, the more complex funerary structures were located at the south-eastern half of the cemetery while the majority of single graves were located everywhere else. The inhumations analysed in this project came from the Av. Francesc Cambó site at the northern end of the site; all were single burials (Aguelo i Mas et al. 2005: 21).

In this cemetery, the archaeologists have suggested that the possible existence of an *aula* with few burials inside. The combination of the chronology of the building with the interest this structure seems to have gathered, for the high density of funerary monuments very close to it, could suggest the tradition of interment *ad sanctum*. If this were confirmed, the necropolis would be contextualised within the Christian faith (Aguelo i Mas et al. 2005: 23).

The existence of a cemetery in Santa Caterina - Av. Francesc Cambó was first identified in two interventions in 1984 and in 1986 directed by M.T. Miró and A. Oliver and J.O. Granados, respectively. However the cemetery was not properly excavated until 1999 – 2002 in a project aiming to understand the chronology and evolution of this site from its Bronze Age occupation until the building of the old Convent of Santa Caterina de Barcelona in the 13th century AD. The excavation, directed by A. Bordas and G. Torres (Aguelo i Mas et al. 2001), recovered 130 individuals, 63 of which were adults individuals who fulfilled the spinal inclusion criteria.

Tarraco – Tarragona Occidental Cemetery (PERI-2)

The ancient Roman city of Tarraco (*Colonia Iulia Triumphalis Tarraco*) was a commercial harbour as well as the capital of *Provincia Hispanis Citerior*, and thus an important political and administrative centre.

Figure 53: Map of Roman Tarraco, location of the palaeo-Christian cemetery (in grey) and of the Peri-2 excavation area (in red) and detail of Peri-2 (Ciurana Prast 2008: 13, 329)

Archaeologically, three different areas have been identified: an oriental and an occidental suburban area and a septentrional peripheral area (indicated in yellow, green and white, respectively in Figure 53). The inhumations analysed in this project came from the Occidental funerary area and therefore all the contextual information given will refer to this area (Ciurana Prast 2011: 1).

The splendour of the Roman city of *Tarraco* was never forgotten by early modern enthusiasts and antiquarians but the first descriptions of burials and funerary monuments only appeared during the last decade of the 19th century and the first significant excavation of the cemeteries took place in the first half of the 20th century. During the 1920s, with the building of the Tobacco factory at the southern part of the city, the excavations directed by Joan Serra Vilaró uncovered a huge tardo-Roman cemetery organised around a Palaeo-Christian basilica and recovered around 443 sepulchres – The Palaeo-Christian Necropolis (Ciurana Prast 2011: 30, 324). From then onwards the modern urban expansion has revealed several archaeological remains thus demonstrating Tarraco's suburban development.

Of all the recorded 443 interments, 431 (97.28%) were inhumations which started appearing in this cemetery in the 1st century AD although few exceptional cases date from the 1st century BC. The remaining burials (12, 2.71%) were cremations dating from the 2nd century BC to the 2nd – 3rd centuries AD (Ciurana Prast 2011: 360). 328 individuals were buried in simple graves, 128 individuals were contained in amphorae (the most common burial container in the 3rd and 4th centuries AD) and the remaining were buried in wooden coffins and sarcophagi (Ciurana Prast 2011: 356). Despite the size of this necropolis, only the areas excavated under the redevelopment Peri-2 project (1995 – ongoing), which recovered 76 individuals, 52 of which were classified as adults. 23 fulfilled the spinal inclusion criteria.

Most of the individuals were found in extended supine position and only four individuals (two infants and two adults) were found in a foetal position. The orientation of the burial was extremely variable (Ciurana Prast 2011: 365-380).

B.3.2.2.2 Early Medieval Catalan sites: Sant Pere de Terrassa and Sant Esteve de Granollers

Plaça de l'Església de Granollers

The site of Plaça de l'Església de Granollers, Barcelona was excavated between July 2002 and January 2005 (Figure 54). During the excavation, nine different chronological phases, from the Roman occupation in the 1st until the 19th centuries AD, were distinguished. The dating of the cemetery found surrounding the Church of Sant Esteve was deduced from the funerary typology which suggest that it remained open from the 4th until the 11th centuries. There is no archaeological evidence of the church, however documentary sources suggest its existance already in the 10th century. The site produced a total of 160 graves, 43 of which were antropomorphic graves known to date between the 10th and the 11th centuries (Moreno and Piera 2007). These securely dated burials were analysed; 18 adults fulfilled the spinal inclusion criteria.

All the individuals were buried west-east (head-feet) although there are minimal cases NE-SW or NW-SE. All the adult individuals were buried in supine position and, following the orthodox Catholic faith, had no grave goods (Moreno and Piera 2007).

Figure 54: Drawing of the archaeological site of Plaça de l'Església de Granollers (from Moreno and Piera 2007: 239)

Sant Pere de Terrassa

The Monumental Complex of the Churches of Sant Pere (Terrassa, province of Barcelona) was used from the 4th to the 13th centuries AD (Figure 55). The Romanic complex descends from a 6th century cathedral linked to the Episcopal Seat of Ègara in the Visigothic period. The conversion of the Visigothic population from Arianism to the Christian faith took place during the last quarter of the 6th century (Jordana Comin 2007: 11). In 713 AD, a Muslim army reached Tarragona and quickly advanced northwards, reaching Ègara. It seems that the new Islamic regime allowed the native population to maintain their traditions, administrative and ecclesiastic organisation (Jordana Comin 2007: 13-14). In general, the Muslim occupation of Catalonia was much shorter than in the southern half of

Spain, as by 785 Girona and by 801 Barcelona were already under Frankish influence. When the Episcopal seats of Girona and Barcelona were recovered, the seat of Ègara fell under the umbrella of the County of Barcelona. In the late 9^{th} century, the urban nucleus of Ègara emerged again with the name of Terrassa. Is worth noting that all the areas newly taken from the Muslims, including Terrassa, during the late-9^{th} and early-10^{th} centuries, were repopulated with families coming from the north of Catalonia (Jordana Comin 2007: 9-16).

Figure 55: Drawing of the Episcopal Complex of Sant Pere de Terrasssa during the Carolingian period (9^{th} – 10^{th} centuries) (from García Llinares et al. 2003: 54)

This necropolis was excavated between 1995 and 2003 under the direction of Antonio Moro (Jordana Comin 2007: 19). 143 graves were excavated and, at least, 208 individuals recovered. Four distinctive periods were identified and characterised by a dominant grave typology: the Palaeo-Christian period (4th – 5th), the Episcopal Complex (5th – 8th), the Carolingian parochial complex (9th – 10th) and the Romanic parochial complex (11th – 13th) (Jordana Comin 2007: 20). For this project, only the individuals from the Carolingian and the Romanic parochial complexes have been selected since they reflect the abovementioned chronology (Table 22). All the individuals (n=104) were selected according to their burial type following the advice of the excavators. As the change of burial type is not drastic, the possibility that some individuals buried during the transition periods were included in the sample should be considered.

The Carolingian burials are typically anthropomorphic, with the shape of the head well differentiated, the grave was usually covered with wood or stone slabs (Figure 56). In the few cases where older non-anthropomorphic graves have been reused, two stones were placed at either side of the head. All the burials are supine and have a west-east orientation (Jordana Comin 2007: 27). Of the total number of 208 individuals recovered, 127 were dated to the early medieval period of which 104 were adults (Jordana Comin 2007: 69) of which 47 fulfilled the spinal inclusion criteria.

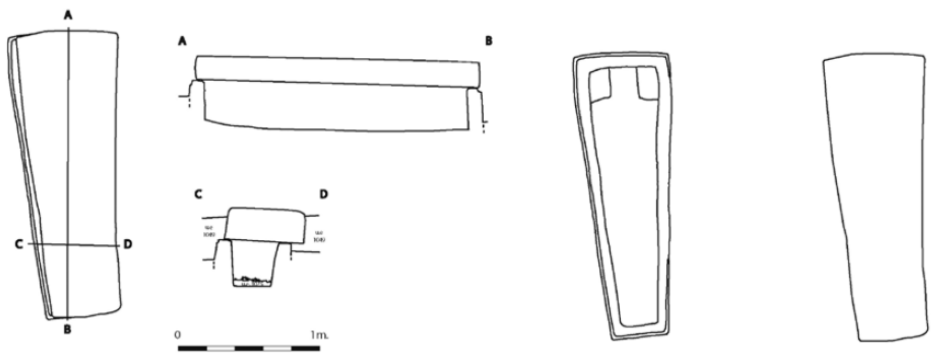


Figure 56: Example of anthropomorphic sarcophagus from Sant Esteve de Canapost (Frigola Triola and Punseti Puig 2012: 365)

B.3.2.2.3 Late Medieval Catalan sites:

Sant Esteve de Canapost

The necropolis of Canapost, Forallac (north-east Catalonia) was excavated between 2004 and 2005 (Figure 57). The cemetery was used from at least the 9th – 10th centuries until the 19th century although the earlier dates could not be verified due to the partial excavation of the site as well as its partial destruction as a result of modern construction. In total 302 burials were recovered (Frigola Triola and Punseti Puig 2012).

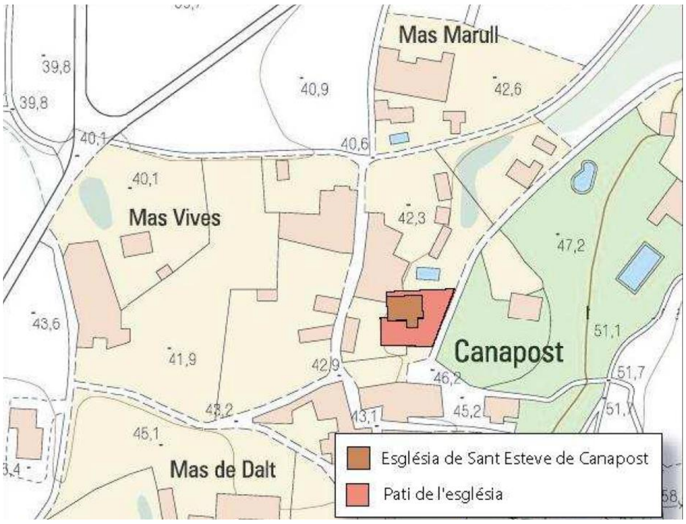


Figure 57: Location of the cemetery of St Esteve de Canapost, Forallac (Frigola Triola 2008, 9)

The burials the archaeologists classified as belonging from the 11th to the 15th centuries are located just above, and often damaging, the earlier anthropomorphic burials. The typology of the burials is the characteristic of the period: boxes of stone slabs, simple graves or simple graves with a stone cover organised in neat rows following an east-west orientation. This same orientation is maintained by the inhumations who were buried in supine with the arms extended (Frigola Triola and Punseti Puig 2012). Three late medieval individuals

(80, 111 and 145) were buried with ceramic globular cooking pots, thus allowing a more specific dating between the late-12th and the early-13th centuries (Frigola Triola 2008).

The exact number of individuals belonging to this period is unknown (Frigola Triola 2008) however the 140 adult individuals were analysed in this project were, according to the archaeological report, most probably from the late medieval period. 32 individuals fulfilled the spinal inclusion criteria.

Sant Miquel d'Olèrdola

The site of Sant Miquel d'Olèrdola (Barcelona) was partially excavated between 2005 and 2007. From the beginning of the 10th century, Olèrdola was the biggest and most important city south of Llobregat River and Barcelona. And by the mid-10th century, it seems that the city was divided into two neighbourhoods, each with its own church and graveyard; Sant Miquel d'Olèrdola inside and Santa Maria outside the city walls (Molist i Capella and Bosch i Casadevall 2012) (Figure 58).

The first written reference of Sant Miquel d'Olèrdola is from 1366 AD, however ^{14}C and stratigraphic analysis indicates that the cemetery was in continuous use from the 9th or even 8th century until 1914. During the most recent archaeological intervention, 178 graves were documented and although the chronological phasing of the site was extremely complicated, the archaeologists attempted their classification depending on burial type and material. The most well-known burials in Olèrdola are the early medieval anthropomorphic graves excavated directly on the stone; because it was in here that this type of grave was first described in

Catalonia, these are also referred as *tombes olerdolianes* (Olèrdola-style graves) (Molist i Capella and Bosch i Casadevall 2012).

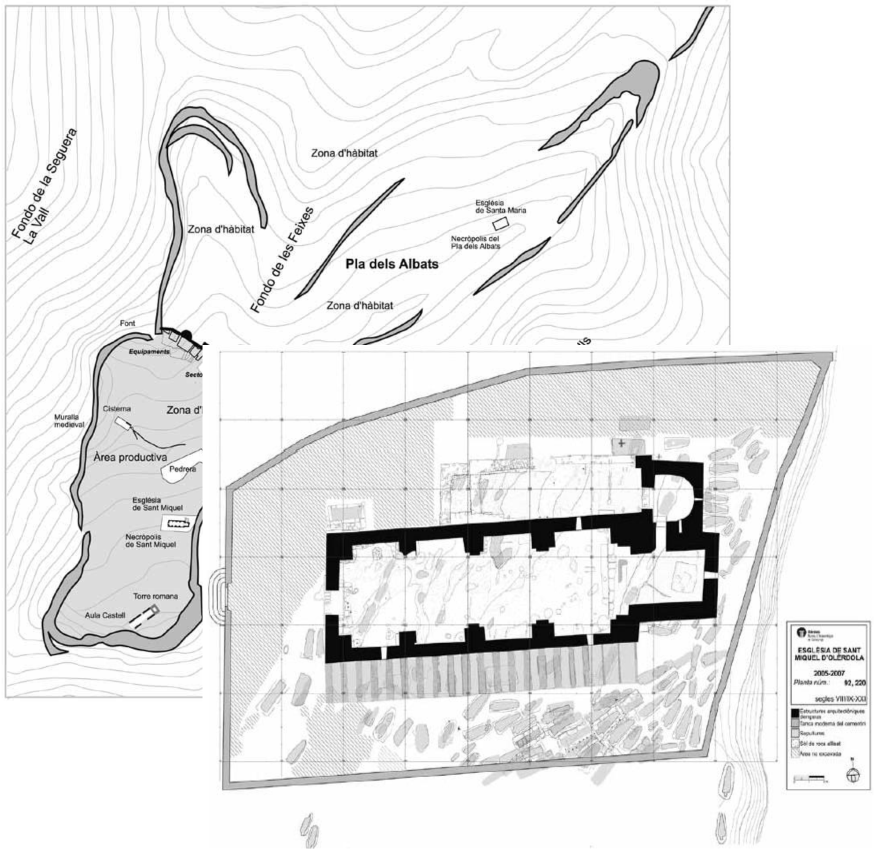


Figure 58: Left: Drawing of the historic complex of Olèrdola. Right: Sant Miquel d'Olèrdola with the excavated medieval and modern graves (Molist i Capella and Bosch i Casadevall 2012: 470, 472)

It is worth noting that, except for the oldest burials, the majority of the inhumations are very poorly preserved. The 26 graves dated from the 12^{th}-13^{th} centuries are of masonry and follow a SW-NE orientation. The radiocarbon dating of an individual buried in this kind of grave produced a calibrated date between 1118 and 1261 (Molist i Capella and Bosch i Casadevall 2012). 10 adult individuals fulfilled the spinal inclusion criteria.

Sant Pere de Terrassa

In the late 10th century, with the last Muslim attack to Barcelona, the Catalan Counties became a cohesive group of entities independent from the Carolingian Frankish rulers. In this period, the society became feudalised thus most of the Catalan population, including Terrassa, was formed by aloer farmers – free landowners of a small patch of land. In Terrassa, the old Episcopal seat of Sant Pere, became the new parochial centre and the rural population it served to progressively increased, possibly around the Monumental Complex. The first references to the town of Terrassa date from 1194 (Jordana Comin 2007: 16-19).

The typology of Romanic burials of Sant Pere de Terrasa, dated from the 11th to the 13th centuries, is typically rectangular without head definition. There are two main types of burial graves, stone graves covered with slabs of wood or stone and simple graves without stone walls but still covered with slabs of wood or stone. The burials are oriented east-west, aligned with the religious buildings (Jordana Comin 2007: 28). Of the total number of 208 individuals recovered, 36 were dated to this late medieval period of which 27 were adults (Jordana Comin 2007: 69), 14 of these fulfilled the inclusion criteria.

Vila-sacra

Located at the north-east corner of Catalonia, the settlement of Vila-sacra does not appear in the documentary sources until the late 10th century. Since its early days, the village was associated to the monastery of Sant Pere de Rodes and its inhabitants. The village had a castle and a church (Sant Esteve) dating from the 11th – 12th centuries (Montalbán Martínez 2009).

The site was excavated between March and July 2006 under the direction of Carmen Montalbán Martínez. During the excavation, the remains from 307 individuals were recovered dating from the medieval period until the 18th century. All the individuals were buried in simple graves, a small number were buried in wooden boxes. Some individuals were accompanied with grave goods such as rosaries and necklaces which could be dated from the early modern period however all the individuals analysed in this project were from the late medieval since the post medieval individuals presented were very poorly preserved (Montalbán Martínez 2009). Of these late medieval individuals, 238 were classified as adults and 33 fulfilled the spinal inclusion criteria.

B.3.2.2.4 Post Medieval Catalan site: Sant Esteve de Canapost

The necropolis of Canapost, Forallac (north-eastern Catalonia) between 2004 and 2005. It seems that the cemetery was used from at least the 9th – 10th centuries until the 19th century however the earlier dates could not be verified due to the partial excavation of the site as well as its partial destruction as a result of modern construction. Of the 302 burials recovered, 73 were securely dated as early modern (Frigola Triola and Punseti Puig 2012).

The majority of the modern individuals were buried in wooden boxes following the normative west-east orientation, although the percentage of burials buried in other orientations, mainly north-south, is higher than in previous periods (Frigola Triola 2008). Furthermore, in contrast with the medieval individuals from this same site, while the supine position is maintained, all the modern individuals were possibly buried with at least one arm crossed over the chest. The archaeologists suggest this could be indicative that these individuals were buried with a rosary as it was traditional in this period (Frigola Triola and Punseti Puig 2012). Of the 73 individuals, 6 adults fulfilled the inclusion criteria.

B.4 DIETARY CHARACTERISTICS THROUGH TIME IN ENGLAND AND CATALONIA

In this chapter, the dietary characteristics of England and Catalonia from the Roman to the post-medieval period will be succinctly discussed. As it has been extensively noted when describing the aetiology of this disease (section A.1.3), DISH is probably related to metabolic imbalances and therefore potentially related to diet. Thus, by exploring the shifts in dietary habits of the past populations, this section aims to give a dietary framework to contextualise the results and provide the grounds to explore the relationship between DISH and diet in ancient populations.

It should be noted that the dietary characteristics described herein will draw a general picture of how diet possibly was; however individual and local adaptations to the "model" diet almost certainly existed. Furthermore, while most of the studies highlight the *types* of cereals, meat and vegetables being consumed, there has not been an exhaustive analysis of *how much* each type of food contributed to the entire diet. One final issue that must be taken into account when trying to understand how the diet of past populations correlates with the prevalence of DISH is that, from a clinical perspective, DISH is a complex condition probably associated to metabolic imbalances and cardiovascular conditions (see sections A.1.3.1 and A.1.3.2). In contrast, in the palaeopathological literature, the aetiology of DISH has been often oversimplified and only diets rich in animal protein (or high caloric diets) have been targeted as potential triggers to the development of the disease (e.g. Spencer 2008: 254; Quintelier et al. 2014).

The dietary information will be combined with the known site characteristics (as described in section B.3.2.2 and B.3.2.3) to outline the probable type of diet followed by the communities analysed according to their environment. Further information about the English and Catalan diet through time can be found in Appendix 5.

B.4.1 Dietary characteristics and isotope data through time in England

Documentary resources and zooarchaeological and isotope data have been brought together to investigate the diet in England from the Roman to the post-medieval period. This section does not aim to compile all the information published about diet but rather to give a broad image of the diet in each time period in a concise manner; a more extensive description of the dietary shifts through time in England can be found in Appendix 5.1. Due to the wealth of research carried out in the British Isles, the information has been tailored to focus on mainland Britain dated as contemporaneous to the sites analysed in here.

B.4.1.1 Romano-British diet

Rural and urban Romano-British settlements show significant variation in environmental and material culture, possibly reflecting unique community traditions, location, environment and economy as well as the influence of the Roman army, available imports and access to urban markets (King 1999; Redfern et al. 2010). It seems also that only in urban areas, the Roman influence permeated all the social strata; in rural areas, only the aristocracy and the elites, eager the increase their status, adopted the ‘Roman lifestyle’ (Cheung et al. 2012).

Documentary sources and archaeological data suggest that Romano-British diet was dominated by terrestrial resources with a high presence of cattle and pig, which, with poultry, eggs and wild game, possibly indicated a high-status diet (Maltby 1997; King 1999; Cool 2006: 98, 102). Rural settlements show higher presence of sheep/goat, retaining the Late Iron Age dietary pattern and showing a lesser Roman influence (King 2001). This suggests that the degree of 'Romanisation' was influenced by social differentiation, access to food and to new and existing dietary patterns (Redfern et al. 2010). The presence of fish, shellfish and fish sauces in Romano-British sites is unequal and dependant on geographical location and the status of the individuals (Cool 2006: 106; Locker 2007).

In Roman Britain, wheat was the most important staple food (White 2000). Barley, oats and rye are recovered in much smaller quantities and its distribution throughout the territory is uneven (Cool 2006: 69, 77). During this period, new fruits, vegetables and herbs were introduced in the Romano-British diet although their distribution is dependent on site location and population characteristics (van der Veen et al. 2007; van der Veen et al. 2008).

The isotope data obtained from Romano-British sites also suggest that the majority of the population followed a terrestrial C_3-plant based diet with a variable input of animal protein and, in some cases, small inputs of marine resources (Richards et al. 1998; Müldner and Richards 2007b; Chenery et al. 2010; Redfern 2010; Chenery et al. 2011; Cheung et al. 2012) (Figure 108, Appendix 5.1.1). It is possible that the fish/shellfish signature is nevertheless masked by the overwhelming terrestrial signature (Redfern et al. 2010). Isotopic data has also shown dietary differences between and within urban and rural communities, between social strata and, in some cases, between sexes (Richards et al. 1998; Fuller et al. 2006, Chenery et al. 2011).

As DISH tends to be associated to the consumption of meat and rich foodstuff, the Romano-British diet which was based on cereals supplemented with variable amounts of meat and fish might lead to a low prevalence of DISH.

B.4.1.2 English Anglo-Saxon diet

The Anglo-Saxon period extends from the fifth to the eleventh century and is divided into three periods: early (410 to mid-seventh centuries), middle (mid-seventh to mid-ninth century) and late (mid-ninth century to 1066AD). The subsistence type rural economy characteristic of the early period (Mays and Beavan 2012) shifted to a more specialised economy aimed to produce an excess of product for exchange starts emerging during the middle period (Pearson 1997; Kenyon 2006; Crabtree 2010). The late Anglo-Saxon period is dominated by a widespread influence of the Christian faith, whose fasting and dietary rules greatly influenced the dietary patterns of both monastic and lay communities from here and onwards (Pearson 1997).

Documentary, archaeological and isotopic diet suggest that the Anglo-Saxon diet was dominated by terrestrial resources with heavy reliance on cattle and sheep/goat (Figure 110, Appendix 5.1.2) (Pearson 1997; Privat et al. 2002; Banham 2004: 58; Hagen 2006: 131; Kenyon 2006; Müldner and Richards 2007b; Crabtree 2010). Dairy products were also consumed (Pearson 1997: 10-11; Banham 2004: 53, 55). Pig may have not been popular although its exact position in the diet of the Anglo-Saxon society is still discussed (Banham 2004:

59; Hagen 2006: 116-122) and chicken and capon were prestige foods (Banham 2004: 57-58; Hagen 2006: 125).

The limited use of marine and freshwater resources seems to have depended on the proximity to the source although preserved fish probably reached the inland settlements and that riverine and marine fauna may have been consumed as a cheap source of protein (Pearson 1997; Privat et al. 2002; Banham 2004: 63; Mays and Beavan 2012). Anglo Saxon settlements until the 10th century produce scarce fish remains and, when found, these are usually freshwater or migratory. From the 11th century and onwards, the presence of marine species increase significantly (Barrett et al. 2004). In the late Anglo-Saxon period, fish was probably consumed by all strata of society and it was suitable for feasts and for fasting days (Hagen 2006: 162-166; Byers 2011). Seaweeds and sea vegetables were possibly also consumed or used as a fodder (Banham 2004: 69; Hagen 2006: 52, Mays and Beavan 2012).

Cereals, mainly wheat and barley consumed as food or drink, were the main staple food in the Anglo-Saxon diet (Hagen 1999: 20; Banham 2004: 13). This was supplemented by a wide variety of pulses, vegetable and fruit (Pearson 1997; Hagen 1999: 33-34; Banham 2004: 29, 34, 43).

It is possible that dietary differences between regions further influenced by social class and ethnic identity ultimately dictated the nutritional status of each different community (Pearson 1997). Nevertheless, in the Anglo-Saxon period, meat became more widely available even when, in the late Anglo-Saxon period, the Church dictated that meat was only allowed to be consumed on non-fasting days. This shift would have made the probability of developing DISH significantly higher in the Anglo-Saxon than during the Romano-British period.

B.4.1.3 Late medieval English diet

In England, the late medieval is generally divided between the earlier (11^{th} – 12^{th} centuries) and the later periods (13^{th} – 16^{th} centuries). This period is very strongly marked by several famines, wars, the Black Death (1348-49) and the War of the Roses (1455-1487) which decimated the population and had a significant impact on the medieval economy. In fact, in the period after the Black Death, survivors of all social status saw an improvement in the quantity and quality of their diet as meat and ale became more affordable and thus its consumption increased (Thomas 2005; Stone 2006; Spencer 2011: 70).

Documentary resources and archaeological and isotopic evidence suggest that late medieval diet was based on cereals, especially wheat (Stone 2006: 11), supplemented with vegetables and fish (Figure 112, Appendix 5.1.3). Marine and freshwater fish was widely available, easily transported and, as a source of protein allowed in fasting days, it became the cornerstone of the late medieval diet (Mays 1997; Barrett et al. 2004: 619; Serjeantson and Woolgar 2006: 130; Müldner and Richards 2005, 2007a, 2007b). Possibly also as a result of the Christian fasting, the consumption of meat was reduce. Cheese and eggs were also consumed in peasant and wealthy households respectively (Spencer 2011: 88, 92). Vegetables and fruit trees from the newly appeared small gardens in towns would have contributed to diet in times of shortage. All the vegetables and roots available for consumption were C_3 plants (Spencer 2011: 71, 91).

The late medieval English diet was defined by a heavy reliance on cereals, an increasing dependency on fish and the consumption of meat only on non-fasting days. Compared to the previous period, this dietary pattern probably reduced the amount of meat consumed which, in its turn, would possibly lead to a lower prevalence of DISH than the observed in the previous Anglo-Saxon population. Fish and meat were, nevertheless, part of the diet and not only a dietary supplement to a vegetarian diet as it was observed in the Romano-British diet therefore it is possible that the prevalence of DISH in this period was slightly higher than in the Romano-British period.

B.4.1.4 Post-medieval English diet

In British archaeology, the period between the 16th and the 19th centuries is known as the post-medieval period. The post-medieval diet was influenced by the Reformation, by the change in the fasting habits and possibly the consumption of more fish (Müldner 2009), by the appearance of market towns and garden markets, by the improvement of the cross-country communications (Roberts and Cox 2003: 294; Spencer 2011: 128, 140, 245) and by the improvement of transport improved food mobility towards the cities. However, it was the exploitation from New World from the late 15th century onwards and the Industrial Revolution that dramatically changed the English food landscape. By the early and mid-19th century, the quality and quantity diet in the over-crowded industrial centres was affected to the level that malnutrition affected almost three-quarters of the inhabitants (Spencer 2011: 267).

The post-medieval diet is dominated by cattle, sheep/goat and pig. Mutton was the most esteemed livestock but the presence of pig in urban and rural sites increased as the period advanced (Albarella 2006: 79; Spencer 2011: 111-112, 150, Gordon 2015: 150). Fish, usually marine but also migratory species, was also an important part of the diet. Freshwater fish was most possibly limited to the wealthy households while stockfish and preserved fish would have been widely available and affordable (Müldner and Richards 2007b; Gordon 2015: 112-114, 174, 179). Cereals, pulses and vegetables remain widely available (Spencer 2011: 110) (Figure 114, Appendix 5.1.4). During the 16th-17th centuries in the West Midlands, where Wolverhampton is located, cattle followed by sheep/goat still dominated the assemblages and characterised by a high presence of pig. By the 17th-18th centuries, West Midlands' are still dominated by cattle and sheep/goat but the proportion of pig slightly decreases. Goat was the predominant domesticate in high status, ecclesiastical and industrial sites (Albarella 2006: 77; Gordon 2015: 151, 160, 166).

After the return Columbus from the Americas a new range of products arrived to Europe and to the British Isles became incorporated into the diet (Spencer 2011: 99). The most notable inclusions were potatoes, maize and sugar cane, the last two being C_4 plants, until now all the vegetables and cereals available had been C_3 plants. Maize was mainly used as a fodder or as a relief food in famine periods and sugar cane became widely available after 1850 when it became cheaper and thus affordable to all levels of society (Mintz 1985: 148; Trickett 2006; Spencer 2011: 42; Beaumont et al. 2013).

The post-medieval English diet is, in many senses, similar to the late medieval as cereals and fish remained the dietary cornerstones. Furthermore, the new products introduced in the late 15th century would not have influence the probability of developing DISH therefore theoretically, the prevalence of DISH between the late and the post-medieval period should be similar. However, it is possible that due to malnutrition and the, on average, shorter life expectancy associated to the industrialisation, the population of Wolverhampton and, in general, the post-medieval populations, show a lower prevalence of DISH compared to the late medieval populations.

B.4.2 Dietary characteristics and isotope analysis through time in Catalonia

Catalonia is located at the north-east corner of the Iberian Peninsula, bordering with France across the Pyrenees in the north and with the Mediterranean Sea in the east. Unlike the vast amount of data available for the study of the diet in the British Isles, the data available for Catalonia is much more limited therefore data from other parts of the Mediterranean basin will be carefully considered. Further information can be found in Appendix 5.2.

B.4.2.1 Roman Catalan, Spanish and Mediterranean diet

Most of the dietary information during the Roman period comes from ancient texts describing the culinary customs of the wealthier classes of the society in Italy or the eastern Mediterranean area (see Purcell 2003; Wilkins 2003). These resources should be used cautiously since the provincial population probably mixed the newly imported Roman habits with their former traditional way of life (King 2001; Cool 2006).

Documentary sources and archaeological and isotope data suggest that the Roman Catalan diet was centred on the Roman triad (cereals, olive oil and wine) supplemented with vegetables, legumes and fruits (Figure 117, Appendix 5.2.1) (Gómez i Pallarès 1996; Garnsey 1999: 13; Ejstrud 2006). In this area, autochthonous C_4 plants (e.g. millet and *Spartina* sp.) probably were either part of the diet or were fed to domesticates (Alonso Martínez 2000; Tafuri et al. 2009; López-Costas and Müldner 2016).

Following Roman trends, pig was possibly the preferred meat although local patterns with high cattle and sheep/goat can be found (Gómez i Pallarès 1996; King 1999, 2001; Genera i Monells et al. 2010; Colominas 2017). Cheese was the only dairy product widely available and chickens, hens and eggs were also an important source of meat and protein (Faas 2006). The status of fish is complex and ambiguous since while it was considered to be for the poor and a sign of destitution, some marine species and seafood were considered a sign of luxury. Furthermore, documentary and epigraphic sources suggest a common consumption of fish (mainly in the coastal sites), however isotope data does not suggest that neither fish nor fish sauces had a significant input in the Roman diet (Gómez i Pallarès 1996; Prowse et al. 2004; Prowse et al. 2005). In fact, most isotope data obtained from Roman sites around the Mediterranean basin has been interpreted as suggestive of a terrestrial C_3 plant-dominated diet with the addition of some meat and a possible little input of marine resources (Fuller et al. 2010; Lightfoot et al. 2012; Nehlich et al. 2012; Rissech et al. 2016).

Thus as it seems that nor meat neither fish were considered a staple foods but more of a supplement to the mainly vegetarian diet (Craig et al. 2009), the probability of developing DISH would be significantly reduced and thus, theoretically, the prevalence of DISH in the Roman Catalan and the Romano-British samples should be similar.

B.4.2.2 Early medieval Catalan, Spanish and Mediterranean diet

The Early Middle Ages are marked historically by the arrival of the Eastern European Visigoths at the Iberian Peninsula and by a greater climate instability which probably affected the agriculture, crop management and local farming strategies. From a historical context perspective, the Catalan Early Middle Age is characterised by the return to the rural lifestyle, with a decrease in trade however the rural but diversified economy thus probably more resistant to food shortages (Henning, 2009; Rottoli 2014; Fàbrega 2016: 19; García-Collado 2016). In this section, only data regarding Christian populations will be investigated.

Documentary sources suggest that the Carolingian Catalan population was heavily reliant on meat (Fàbrega 2016: 46) however there is a significant lack of bioarchaeological published data from the early medieval population in Catalonia and Spain (Hoffmann 2005). Documentary sources and archaeological and isotope data suggest that the early medieval diet around the Mediterranean area was dominated by C_3-plants and terrestrial animal protein, supplemented by vegetable and pulses and a small direct or indirect input of C_4 plants (Figure 120, Appendix 5.2.2) (Alonso Martinez 2005; Ruas 2005; Sirignano et al. 2014; MacKinnon 2015: 131; García-Collado 2016).

Terrestrial meat was possibly obtained primarily from sheep/goat and cattle. The presence of pig varies significantly between sites and it has been suggested that only the people who could afford to rear them, actually consumed it, suggesting that the consumption of pig was a symbol of high status (Morales Muñiz 1992; Sirignano et al. 2014; Vigil-Escalera Guirado et al. 2014). By the fifth and sixth centuries, the consumption of fish in fasting days was encouraged by the new Christian faith and while some isotope data might suggest the consumption of this resource (Lightfoot et al. 2012; Quirós Castillo 2013: 26-27) the paper of fish in the early medieval diet has been scarcely investigated (Hoffman 2005).

In complete contrast with the almost vegetarian diet of the Roman Catalan society, it seems that the early medieval population relied heavily on meat which would have increased the probability of developing DISH.

B.4.2.3 Late medieval Catalan, Spanish and Mediterranean diet

In medieval Catalonia (11th – 15th centuries AD), the ecclesiastic calendar had a very strong influence on the popular diet. 150 fasting days were imposed in which only one big meal was allowed (Thibaut i Comalada 2006: 37-38). The Islamic influence on the diet in the entire Peninsula cannot be underestimated and while Catalonia was under Arab occupation for less than a century, its influence is still noticeable as two of the most important products they introduced were rice and sugar cane (Thibaut i Comalada 2006: 64-65).

Cereals were the cornerstone in the late medieval Catalan diet; the type of cereal consumed was possibly associated to the social status and the religious affiliation (Bertrán Roigé 1999; Maranges 2006: 249-250; Alexander et al. 2015). During Lent and on fasting or “fish” days, meat and fats were not allowed thus oil, wine, wheat and fish in combination with legumes, nuts, vegetables, and dairy products were consumed (Maranges 2006: 45; Thibaut i Comalada 2006: 38-41). Meat, considered essential for human subsistence, was possibly available to all levels of society; goat was the most popular one however cattle and pig were also consumed (Maranges 2006: 55, 57; Fàbrega 2016: 30).

Marine fish (fresh and possibly dried) and seafood from the Mediterranean area were considered staples (Maranges 2006: 157-159; Alexander et al. 2015; Fàbrega 2016: 30; Contreras Mas 2017: 69). There are very few references to the consumption of freshwater fish which, while considered of high status, may have been exploited by the inland peasants as an easy resource (Maranges 2006: 157-159; Mundee 2010b; MacKinnon 2015; Fàbrega 2016: 30; Contreras

Mas 2017: 69). Pulses and a wide variety of vegetables, fruits and nuts were also available to all levels of the society (Maranges 2006: 272).

The late medieval Catalan diet was dominated by C_3 plants with a possible variable input of C_4 plants (Figure 122, Appendix 5.2.3). The Christian fasting seems to have influenced the consumption of fish and seafood as meat was consumed by all members of society but only the days when allowed. With this dietary pattern, it is possible that the prevalence of DISH in this population might have decreased in comparison to the previous early medieval period when meat was a dietary cornerstone.

B.4.2.4 Post-medieval Catalan, Spanish and Mediterranean diet

After the 16th century, the European diet (including Spanish and Catalan diet), was significantly changed by the arrival of new foods from the New World (Roden 2012: 33; MacKinnon 2015: 48). However in continuation with the late medieval diet, the post-medieval diet in Catalonia and Spain was dictated by the Catholic Church. It is worth noting that post-medieval or early modern archaeological research in Catalonia and Spain is almost non-existent.

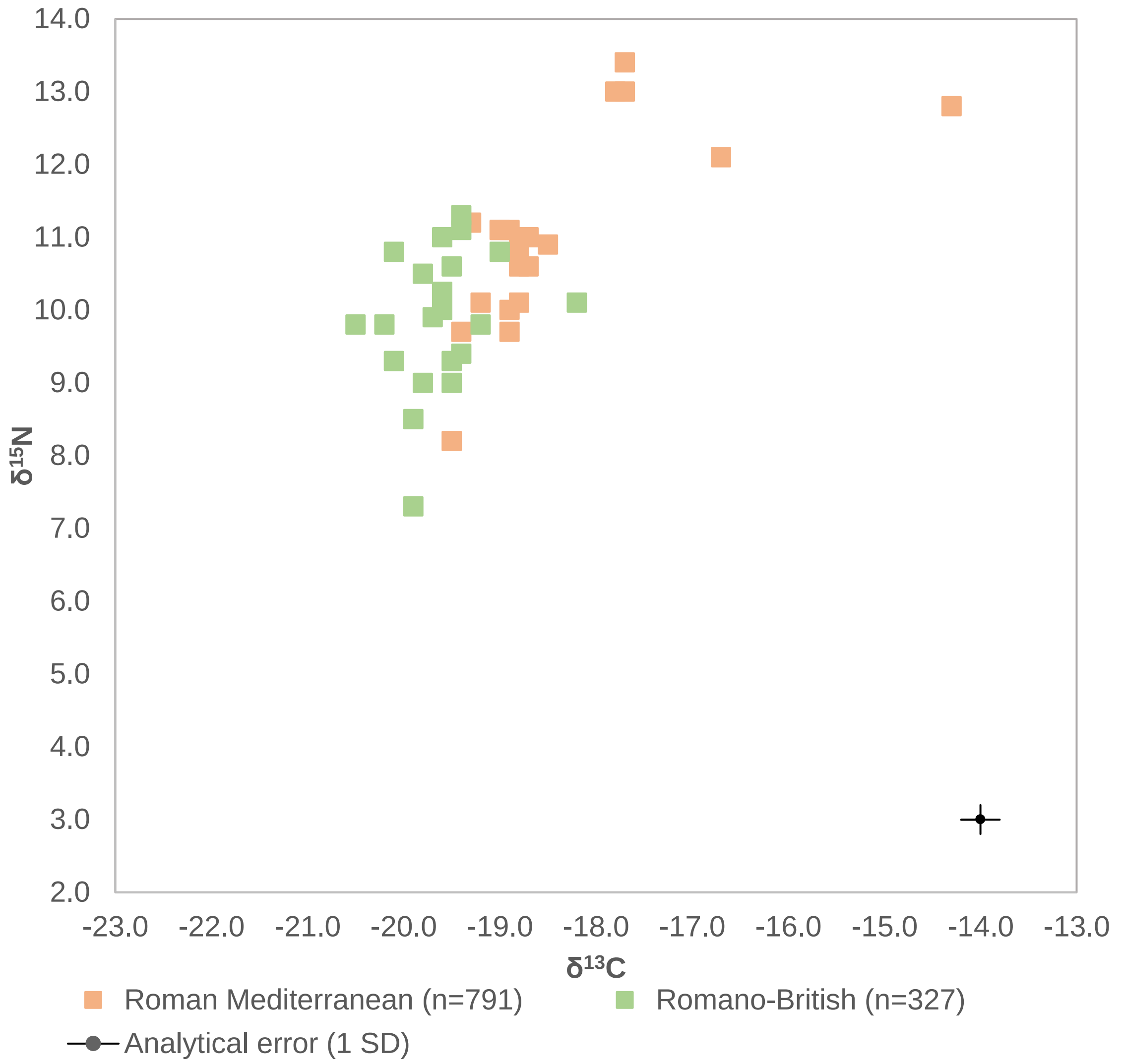
Documentary sources suggest that post-medieval Spanish diet was very class-specific. The nobility ate great quantities of meat, white fish, fruit, wine, chocolate and small amounts of vegetables and resisted the adoption of the New World products (Roden 2012: 40). Meanwhile, the diet of the poor was dominated by vegetables, freshwater fish, cod and herring (Fagan 2006: 244). When allowed, small amounts of meat (mainly pig but also chicken and eggs) were also consumed (Roden 2012: 47). Potatoes, beans and maize among other New World vegetables soon replaced or supplemented the traditional crops of grains, legumes and chestnuts (Roden 2012: 45-46). However it must be taken into account that diet staples changed between regions, with the Mediterranean coast relying more heavily on vegetables and fruit and possibly chicken, fish and eggs (Roden 2012: 48) so the adoption of the New World foods might not have been a widespread phenomenon (MacKinnon 2015).

Nevertheless, the post-medieval diet was a C_3 terrestrial diet supplemented with fish, variable amounts of meat depending on the status and a direct or indirect variable inclusion of C_4 plants (Figure 125, Appendix 5.2.4). The diet followed by the majority of the population is therefore not very different to the one described for the late medieval Catalan population and therefore, theoretically, the prevalence of DISH should remain constant.

In sum, the analysis of English and Catalan dietary characteristics through time suggest that for both populations, the prevalence of DISH should be the lowest during the Roman periods as the diet was dominated by cereals and vegetables with variable, but possibly small, consumption of rich foods (i.e. meat). The same shift to a meat–dominated diet has been identified in the Anglo-Saxon and the early medieval Catalan populations; a shift that most probably will see the prevalence of DISH increase in a very significant magnitude compared to the previous period. The strong influence of the Catholic Church and the imposition of fasting days when meat was not allowed in the late medieval English and Catalan period led to the increase in the consumption of fish. While some marine resources could have been considered high caloric (e.g. whale and porpoise), cod, the most available fish, is relatively low in fat. It is therefore probable that the prevalence of DISH is reduced in the late medieval period for both regions. The diet followed by the post-medieval English and Catalan populations is quite similar to the late medieval one however the industrialisation of the English cities has been shown to have had an impact on the health and diet of the local population, thus potentially reducing the prevalence of DISH. In Catalonia, the influence of the Catholic Church remained and the industrialisation period also characterised the post-medieval Catalan period, to the knowledge of the author no research has been carried out to assess its impact on the society thus it is not really possible to infer how it would have influenced the prevalence of DISH in the post-medieval Catalan population.

B.4.3 Comparison of expected differences in dietary habits between England and Catalonia

Romano-British diet is dominated by terrestrial resources with a high presence of cattle and pig (possibly in high status household). Rural population seem to have preferred sheep and goat. In comparison, Roman Catalan diet was centred on the Roman triad (cereals, olive oil and wine) supplemented with legumes with little presence of animal product. Documentary sources and archaeological data suggest that fish, shellfish and fish sauces were consumed by Romano-British and Roman Catalan communities, however isotope data does not suggest that the neither populations relied heavily on this resource. It is possible that the consumption of fish was unequal and dependant on geographical location and social status and so its isotopic signature might have been masked by the overwhelming terrestrial signature.

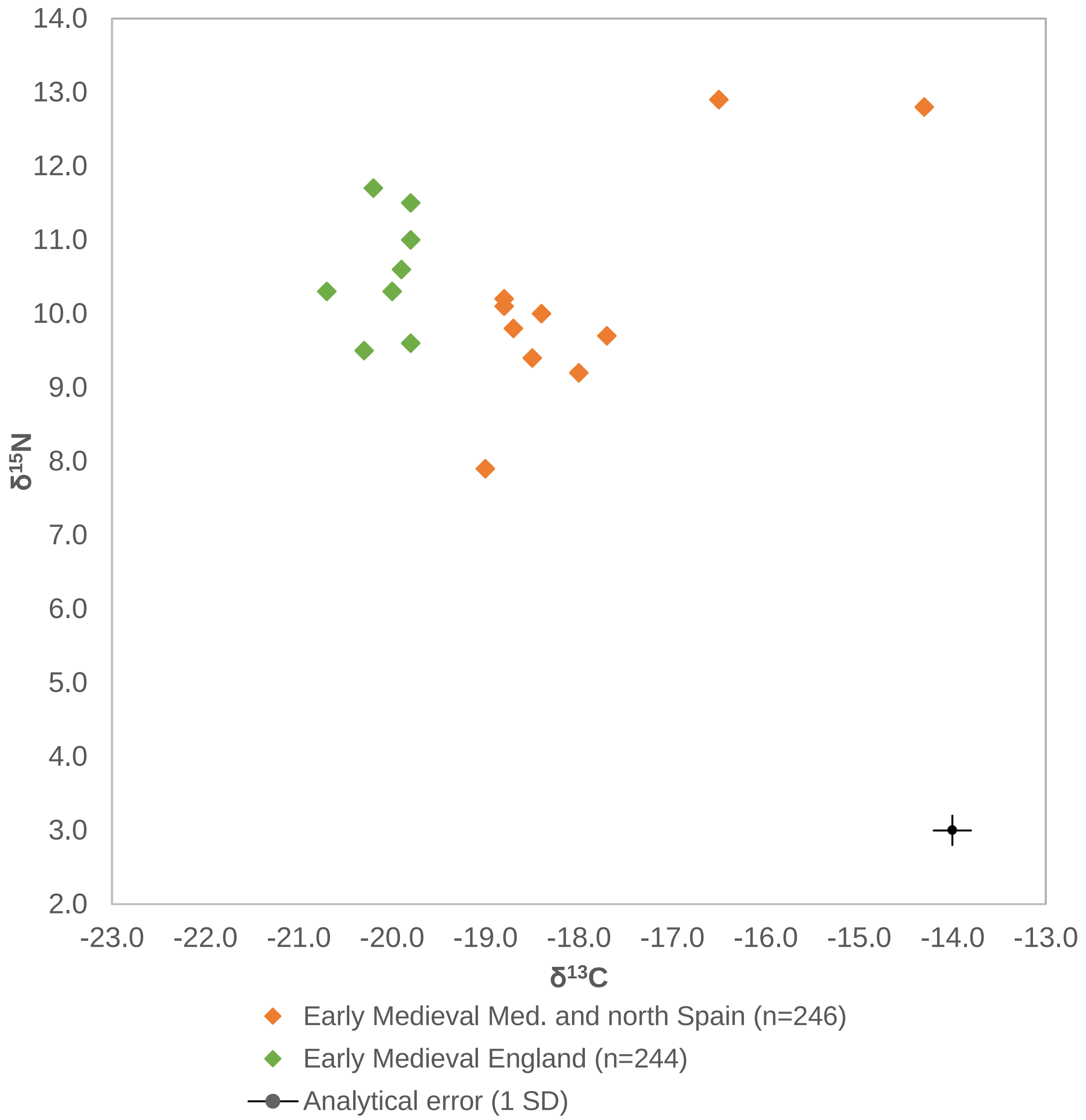


Graph by author. Data from: Richards et al. (1998), García et al. (2004), Prowse et al. (2004, 2005), Fuller et al. (2006, 2010, 2012), Müldner and Richard (2007b), Craig et al. (2009), Keenleyside et al. (2009), Redfern et al. (2010), Chenery et al (2011), Cheung et al. (2012), Lightfoot et al. (2012), López-Costas and Müldner (2016) and Rissech et al. (2016). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 59: Comparison of mean average isotope values from Romano-British and Roman Mediterranean and Atlantic populations.

Therefore during the Roman period, both populations followed a terrestrial C_3-based diet should be expected (Figure 59). The only possible difference is a small carbon enrichment due to the consumption of autochthonous C_4 plants in the Catalan population.

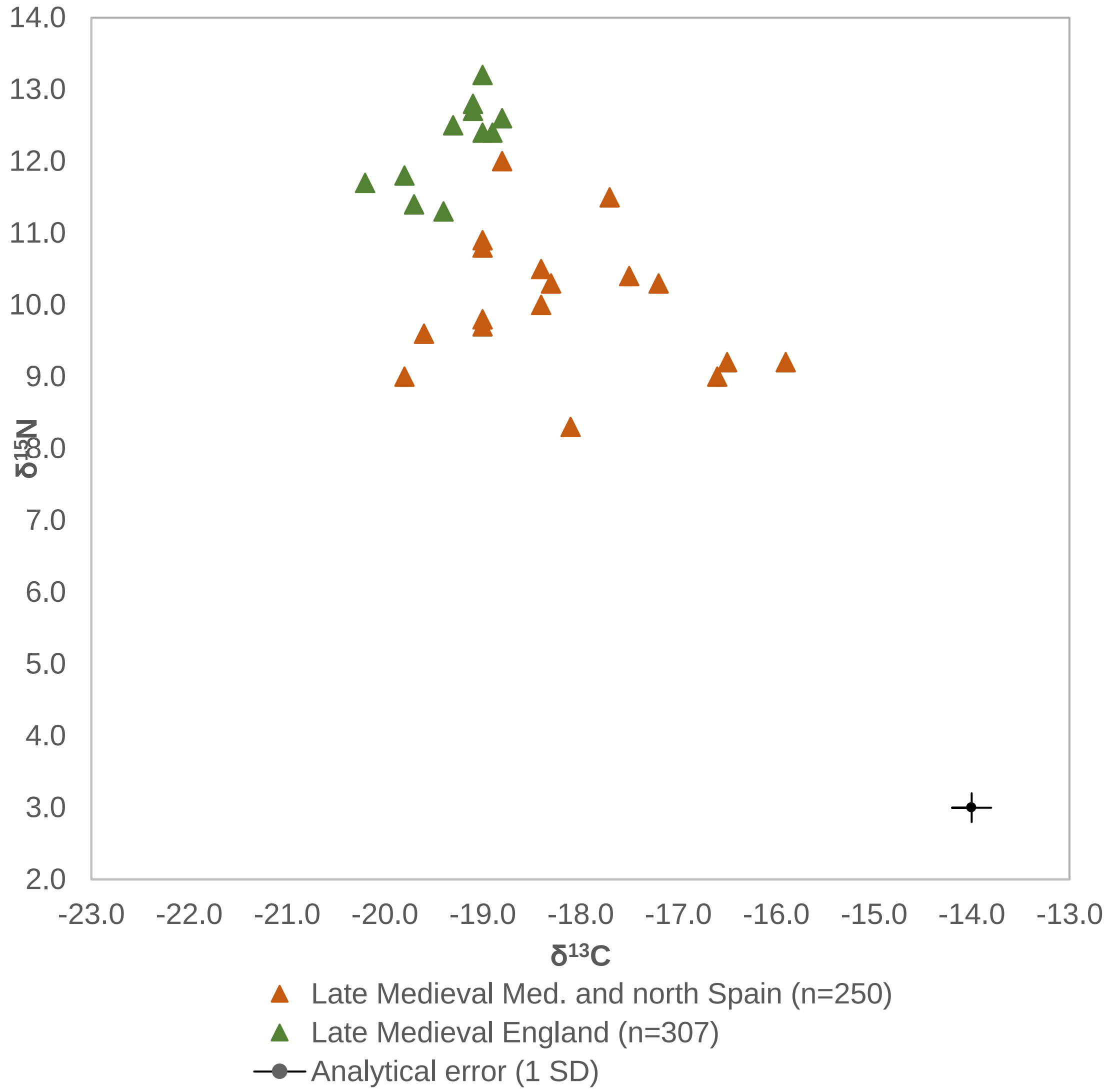
Anglo-Saxon and early medieval Catalan diets were dominated by C_3-plants, terrestrial resources with heavy reliance on cattle and sheep/goat supplemented with a wide variety of vegetables, fruit and pulses. The use of marine and freshwater resources in England possibly depended on the proximity to the source although preserved fish might have reached inland settlements. By the fifth and sixth centuries, in Catalonia, fish was consumed possibly on fasting days; as encouraged by the new Christian faith. Isotope analysis from English sited tend to show higher nitrogen ratios, possibly suggesting a slightly higher intake of fish compared to the Mediterranean sites while the slightly higher carbon ratios in the Mediterranean sites suggests a diet possibly supplemented with a small direct or indirect input of C_4 plants (Figure 60).



Graph by author. Data from: Privat et al (2002), Müldner and Richards (2007b), Mays and Beavan (2012), Lightfoot et al. (2012), Haydock et al (2013), Quirós del Castillo (2013), MacKinnon (2015), García-Collado (2016) and López-Costas and Müldner (2016). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 60: Comparison of mean average isotope values early medieval English and Atlantic and inland Spanish populations

As with in the previous periods, the late medieval English and Catalan diet was based on cereals, especially wheat, although in the Mediterranean area other cereals (e.g. barley, millet and sorghum) were also widely used. In England, peasant diet was probably vegetable-based, with fish, dairy, eggs and small quantities of meat as sources of protein. In contrast, in Catalonia and Spain, meat, pulses, vegetables, fruits and nuts were possibly available to all levels of society; on fasting days, fish (marine and seafood) and dairy products were the main source of protein.

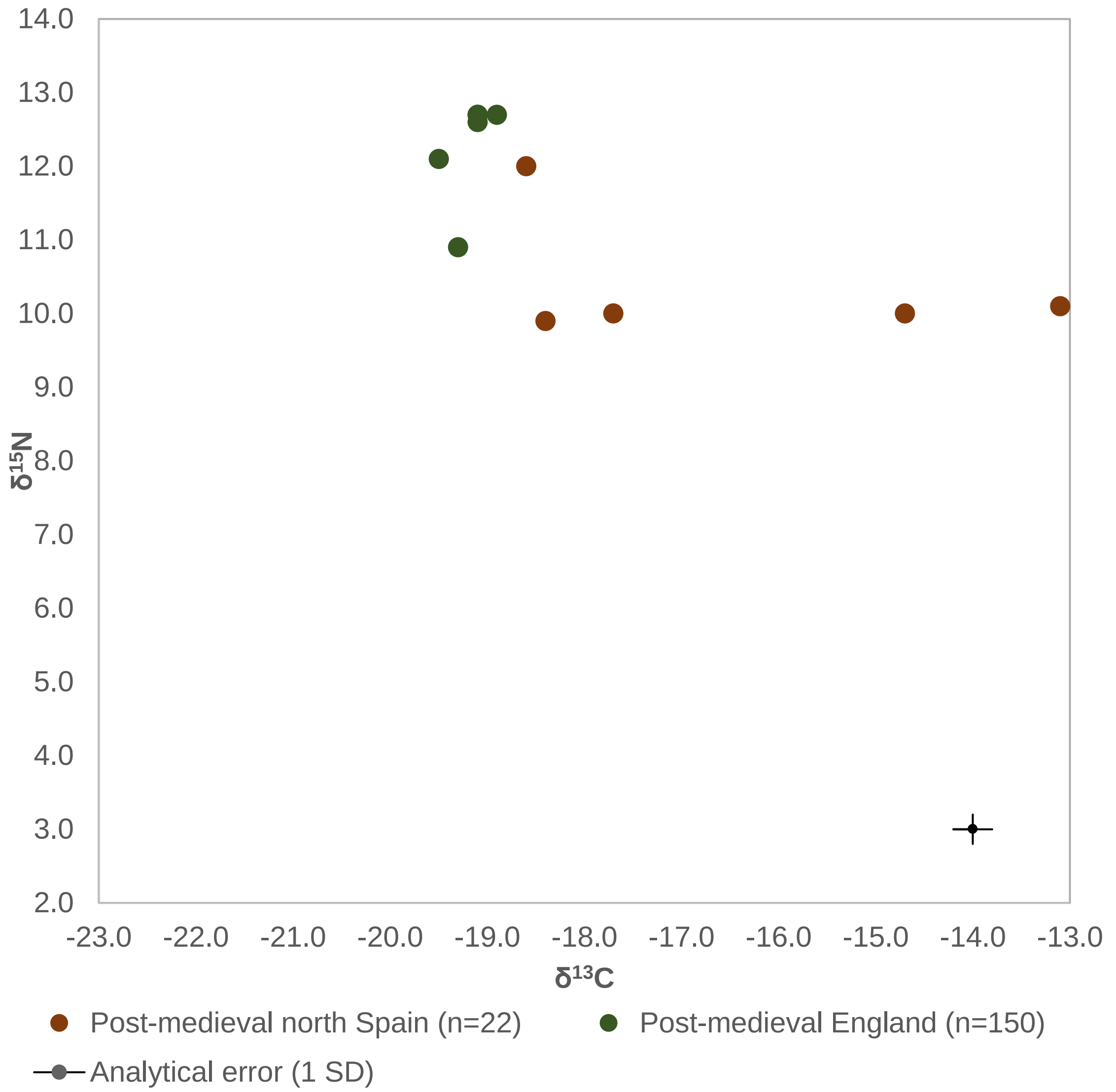


Graph by author. Data from: Müldner and Richards (2005, 2007a, 2007b), Mundee (2010a in: Quirós del Castillo (2013), 2010b), Lubritto et al. (2013), Quirós del Castillo (2013), Alexander et al. (2015) and MacKinnon (2015). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 61: Comparison of mean average isotope values from late medieval English and Atlantic and inland Spanish populations

Due to the imposition of Christian fasting, in both regions, fish, became the cornerstone of the diet however the majority of the late medieval English sites show higher nitrogen values compared to the Mediterranean sites suggesting that English populations had a heavier reliance on this resource. The wider distribution of the Mediterranean isotope data possibly indicates that these populations had a more varied diet than their English counterparts (Figure 61).

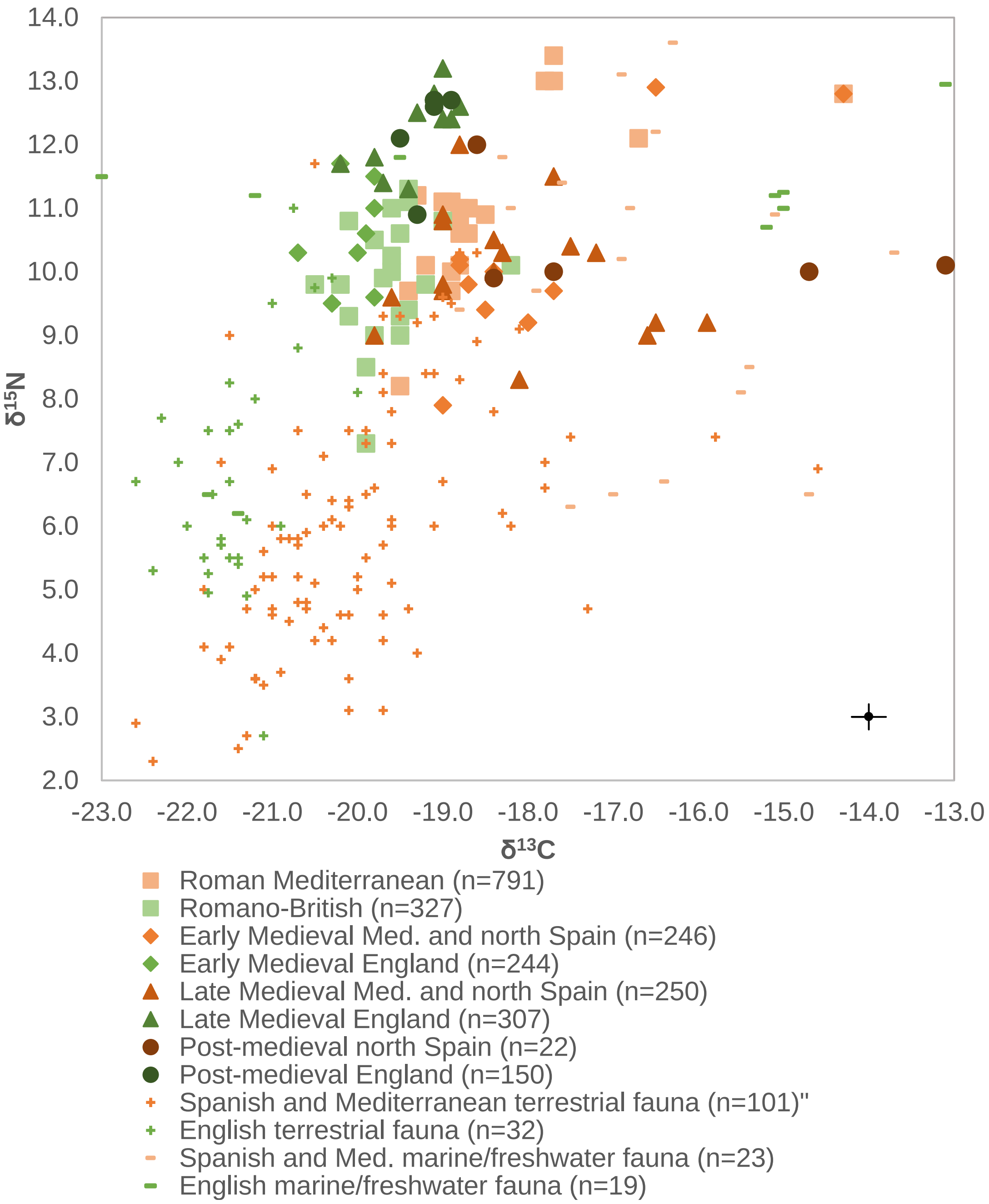
The post-medieval English and Catalan diet was significantly influenced by the incorporation of new foods brought from the Americas. The most notable inclusions were potatoes, maize and sugar cane, the last two being C_4 plants. In England, diet was dominated by cattle (reared for meat and milk), sheep/goat and pig. Fish was an important part of the diet with stockfish and preserved fish being widely available and affordable. Cereals, pulses and vegetables were also widely available. In northern Spain, New World and autochthonous vegetables, small amounts of meat, freshwater fish, cod and herring dominated the diet of the poor. It is possible that Mediterranean regions (i.e. Catalonia) relied more heavily on vegetables, fruit, chicken, fish and eggs than the northern regions, however the lack of archaeological data makes it very complicated to clearly define the diet in post-medieval Catalonia. Figure 62 shows the English population have higher nitrogen values perhaps indicating a stronger reliance on fish while the significantly high carbon values in the northern Spanish populations could indicate a higher intake of C_4 plants (e.g. millet, maize).



Graph by author. Data from: Trickett (2006), Müldner and Richards' (2007b), Beaumont et al. (2013) and MacKinnon (2015). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 62: Comparison of average isotope values from post-medieval English and Atlantic and inland northern Spanish populations

To summarise, English and Catalan populations followed a mainly terrestrial C_3-based diet through time however significant differences exist. First, the trends in fish consumption are slightly different as the English populations seem to have increased their reliance on this resource through time. Isotopically, the majority of the Mediterranean populations do not show a significant variation of fish consumption as this resource was probably readily available through time (Figure 63). Second, Mediterranean populations seem to have had a constant input of C_4 plants in their diet, either directly or indirectly consumed, as they consistently show slightly higher carbon isotope values compared to their English counterparts. However isotope data suggest still suggests that C_3 resources dominated over the C_4 ones. Interestingly, the animal isotopic baseline shows a similar distribution compared to the human remains – in general, Mediterranean terrestrial fauna shows higher carbon isotope values than English terrestrial (Figure 63) – suggesting that other factors such as climate and differences in the animals themselves may have influenced the results obtained from the human remains. It is then possible to suggest that only the major differences in the isotope signatures between English and Mediterranean populations are probably related to differences in dietary patterns, while the minor shifts could be related to climate or to the animals themselves.



Graph by author. Data from: Richards et al. (1998), Garvie-Lok (2001), Privat et al (2002), García et al. (2004), Prowse et al. (2004, 2005), Fuller et al. (2006, 2010, 2012), Müldner and Richard (2005, 2007a, 2007b), Trickett (2006), Bourbou and Richards (2007), Craig et al. (2009), Mundee (2010a in: Quirós Castillo (2013), 2010b), Keenleyside et al. (2009), Redfern et al. (2010), Chenery et al (2011), Cheung et al. (2012), Lightfoot et al. (2012), Mays and Beavan (2012), Beaumont et al. (2013), Haydock et al. (2013), Lubritto et al. (2013), Quirós Castillo (2013), Salazar-García (2014), Sirignano et al. (2014), Alexander et al (2015), MacKinnon (2015), García-Collado (2016), López-Costas and Müldner (2016) and Rissech et al. (2016). Data represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 63: Comparison of average isotope values of human and animal remains from English and Mediterranean, Atlantic and inland northern Spanish populations through time

B.5 RESULTS

In this chapter, the results obtained in the analysis of the archaeological human remains from Catalonia and England will be explored. The evaluation of the demographic profiles of each sample will be followed by the study of the prevalence of DISH in the English and Catalan samples and a comparative diachronic analysis of DISH between the two regions. As previously indicated, the relationship between the spinal and the extra-spinal manifestations of this condition will be further explored in the framework of the archaeological context. Finally, the findings regarding the co-morbidities between DISH and other nutrition-related or metabolic conditions will also reported.

As a general rule unless otherwise stated, the values in the table represent the observed values with the corresponding percentages in brackets. These percentages have been used to create the corresponding figures. In each case, it will be made clear how these values have been calculated.

B.5.1 Demographic evaluation of the samples studied

The demographic profiles of all the samples studied were compared to ensure that English and Catalan samples from the same period or as a whole were not significantly different and therefore could be directly compared. To allow a meaningful demographic evaluation, as it was stated in the methods section (B.2.2.1), all the individuals initially identified as adults were classified in three different groups (young adult: 18 – 39.9; middle adult: 40 – 59.9; old adult: over 60) depending on the maximum likelihood of age as indicated in the output of the transition analysis software at 95% likelihood using the archaeological prior. A fourth category (*adult*) grouped together all the adult individuals whose age could not be estimated due to preservation problems. In this series of results, the percentage is the representation of each demographic subgroup within the total of the sample.

B.5.1.1 Roman samples

The demographic profiles from the Romano-British sites (Bladock, Kingsholm and Gambier Parry Lodge) are remarkably similar to that of the Roman Catalan sites (Tarraco and Santa Caterina). In both cases, there is a higher number of young and old individuals and with a lower presence of middle aged adults. The sex distribution of both samples is also similar, with a comparable percentage of male individuals and a slightly higher percentage of indeterminate individuals in the Roman Catalan sample (Tables 25 and 26, Figures 64 and 65). See Appendix 4.1 and 4.2 for the specific data regarding the Romano-British and the Roman Catalan individuals.

Table 25: Distribution of the Romano-British individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	14 (18.9)	3 (4.1)	16 (21.6)	3 (4.1)	36 (48.6)
Males	11 (11.9)	6 (8.1)	12 (16.2)	2 (2.7)	31 (41.9)
Indeterminate	3 (4.1)	1 (1.4)	2 (2.7)	1 (1.4)	7 (9.5)
TOTAL	18 (24.3)	10 (13.5)	30 (40.5)	6 (8.1)	74

Table 26: Distribution of the Roman Catalan individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	7 (8.0)	8 (9.2)	15 (17.2)	5 (5.7)	35 (40.2)
Males	13 (14.9)	3 (3.4)	14 (16.1)	6 (6.9)	36 (41.4)
Indeterminate	3 (3.4)	0 (0.0)	3 (3.4)	10 (11.5)	16 (18.4)
TOTAL	23 (26.4)	11 (12.6)	32 (36.7)	21 (24.1)	87

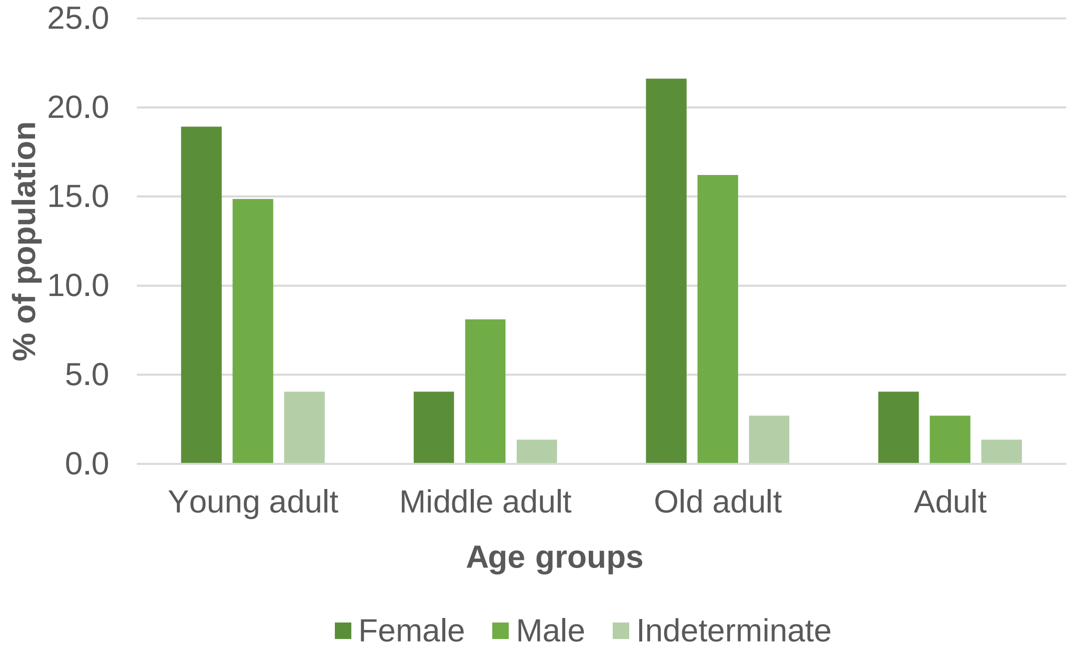


Figure 64: Demographic profile of the Romano-British sample (n=74)

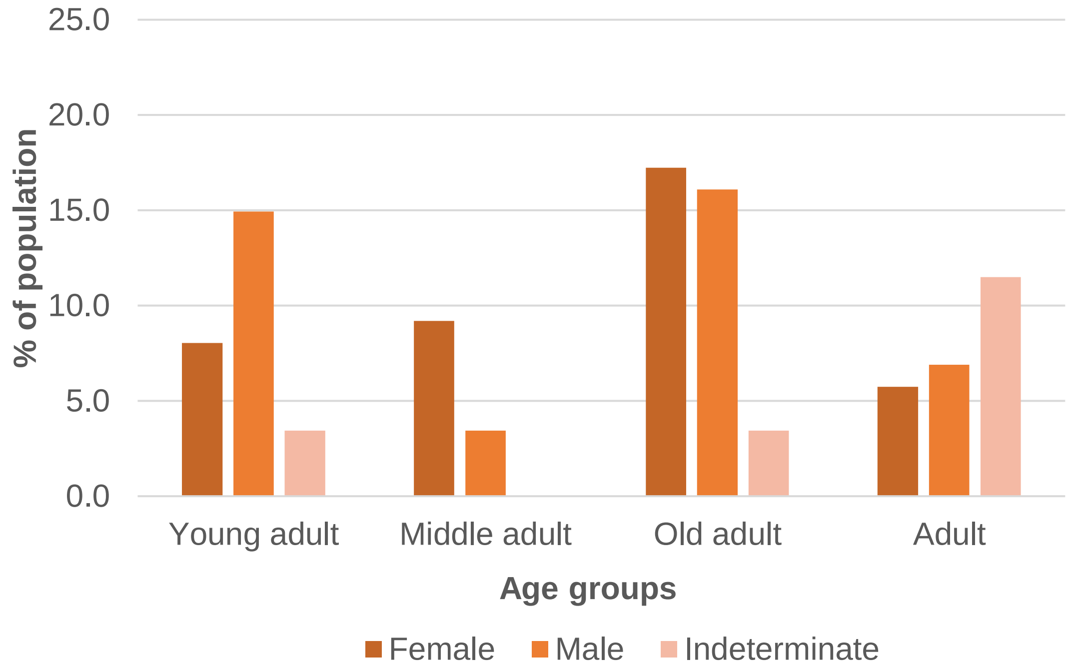


Figure 65: Demographic profile of the Roman sample from Catalonia (n=87)

Once the individuals classified as *adults* have been removed, the statistical analysis for the Roman Catalan and the Romano-British samples indicate that the age profile of both samples are not siginicantly different (Independent samples Kruskal-Wallis test, p=0.506). Once the individuals classified as *indeterminate* were removed, the Chi-squared tests also indicated that the sex distribution of both samples was not significantly different (X^2=0.272; p=0.602). These results suggests that from now on, these samples are directly comparable.

B.5.1.2 Early medieval samples

The demographic profile observed in the Catalan and the English Roman period is replicated in the the Anglo Saxon (Raunds) and early medieval Catalan (Sant Pere de Terrassa and Sant Esteve de Granollers) samples with a high prevalence of young and old individuals and a lower presence of middle-age adults (Tables 27 and 28, Figures 66 and 67). See Appendix 4.3 and 4.4 for the specific data regarding the early medieval English and Catalan individuals.

Table 27: Distribution of the Anglo-Saxon individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	19 (16.4)	11 (9.5)	18 (15.5)	13 (1.2)	61 (52.6)
Males	17 (14.7)	4 (3.4)	21 (18.1)	5 (4.3)	47 (40.6)
Indeterminate	4 (3.4)	1 (0.9)	0 (0.0)	3 (2.6)	8 (6.9)
TOTAL	40 (34.5)	16 (13.8)	39 (33.6)	21 (18.1)	116

Table 28: Distribution of the early medieval Catalan individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	15 (23.1)	5 (7.7)	6 (9.2)	5 (7.7)	31 (47.7)
Males	10 (15.4)	3 (4.6)	14 (21.5)	2 (3.1)	29 (44.6)
Indeterminate	0 (0.0)	1 (1.5)	4 (6.2)	0 (0.0)	5 (7.7)
TOTAL	25 (38.5)	9 (13.8)	24 (36.9)	7 (10.8)	65

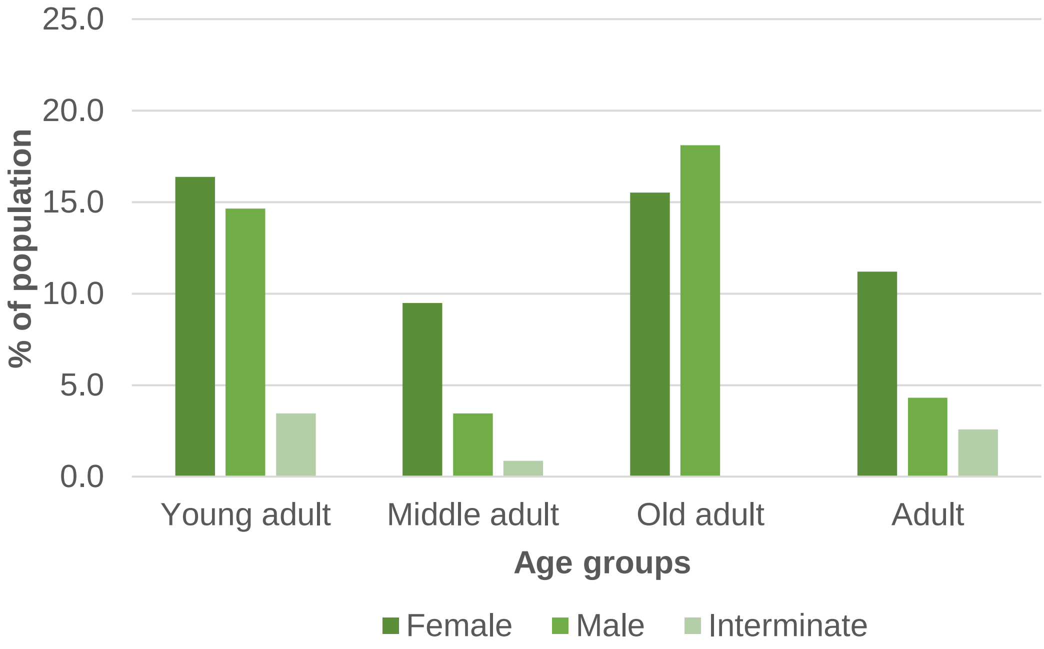


Figure 66: Demographic profile of the Anglo-Saxon sample (n=116)

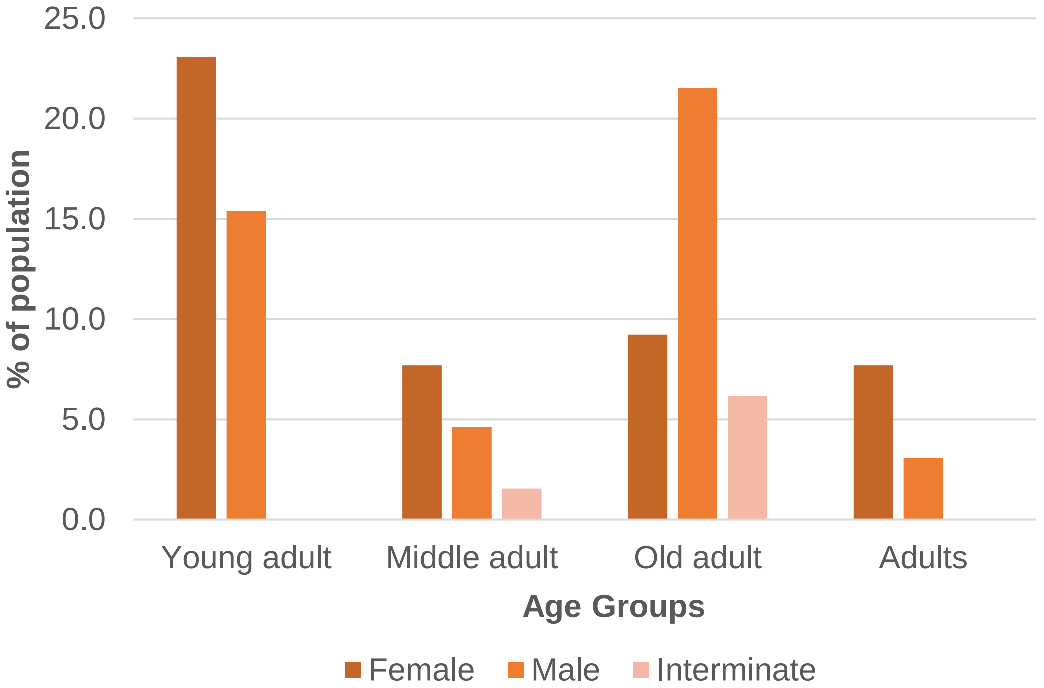


Figure 67: Demographic profile of the early medieval sample from Catalonia (n=65)

As with the Roman samples, individuals classified as *adults* or *indeterminate* have been not been included in the statistical analysis. The Independent samples Kruskal-Wallis and the Chi-squared tests applied on the early medieval Catalan and the Anglo-Saxon samples indicate that the age profile and sex distribution of both samples are not significantly different ($p=0.965$ and $X^2=0.444$; $p=0.505$, respectively). These results suggests that from now on, these samples are directly comparable.

B.5.1.3 Late medieval samples

The demographic profiles of late medieval English (York Fishergate House) and Catalan (Sant Esteve de Canapost, Sant Miquel d'Olèrdola, Sant Pere de Terrassa and Vila-Sacra) samples seem noticeably different to the ones previously analysed. In the English sample has a high number of female individuals in the middle age group (Table 29, Figure 68); a pattern differs from the demographic profiles observed in the Roman and the early medieval samples. In contrast, the Catalan sample follows the same pattern of higher prevalence of young and older adults compared to the middle adults (Table 30, Figure 69). However, once the individuals classified as *adults* have been removed, the statistical analysis for the late medieval British and Catalan samples indicate that the age profile of both samples are not significantly different (Independent samples Kruskal-Wallis test, $p=0.229$). And once the individuals classified as *indeterminate* were removed, the Chi-squared tests also indicated that the sex distribution of both samples was not signifcantly different ($X^2=0.71$; $p=0.790$). The discrepancy between what it is observed comparing Figures 68 and 69 and the statistical results is possibly related to the fact that although the overall percentage of females is similar to that of males the age distribution within each sex is different. This asymmetric distribution means that any demographic comparison considering age and sex will have to be carefully done. See Appendix 4.5 and 4.6 for the specific data regarding the late medieval English and Catalan individuals.

Table 29: Distribution of the late medieval English individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	11 (17.2)	12 (18.8)	7 (10.9)	4 (6.3)	34 (53.1)
Males	9 (14.1)	1 (3.1)	15 (23.4)	2 (3.1)	28 (43.8)
Indeterminate	0 (0.0)	0 (0.0)	1 (1.6)	1 (1.6)	2 (3.1)
TOTAL	20 (31.3)	13 (20.3)	23 (35.9)	7 (10.9)	64

Table 30: Distribution of the late medieval Catalan individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	11 (12.4)	6 (6.7)	14 (15.7)	8 (9.0)	39 (43.8)
Males	6 (6.7)	2 (2.2)	17 (19.1)	5 (5.6)	30 (33.7)
Indeterminate	3 (3.4)	4 (4.5)	5 (5.6)	8 (9.0)	20 (22.5)
TOTAL	20 (22.5)	12 (13.5)	36 (40.5)	21 (23.6)	89

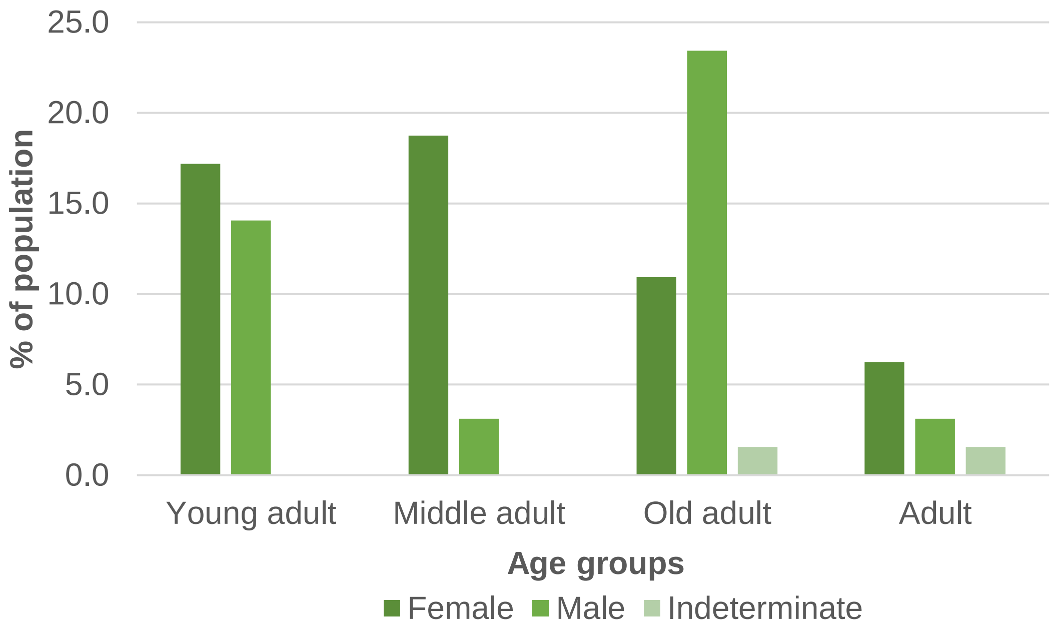


Figure 68: Demographic profile of the late medieval sample from England (n=64)

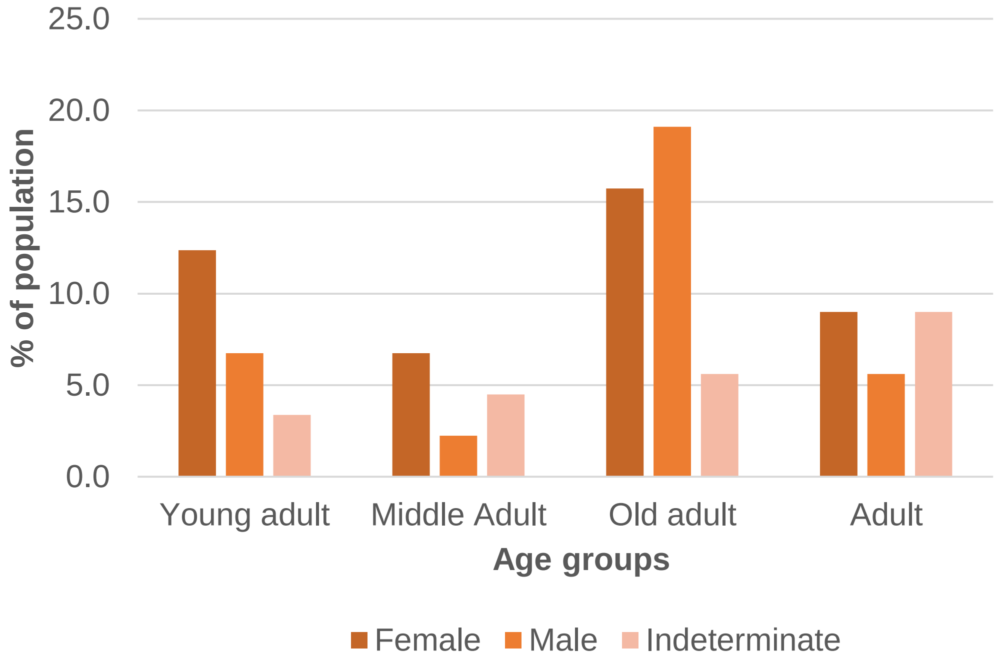


Figure 69: Demographic profile of the late medieval sample from Catalonia (n=89)

B.5.1.4 Post-medieval samples

No statistical analyses have been run to compare the Post-medieval English (Wolverhampton) and the Catalan (Sant Esteve de Canapost) samples because the Catalan sample is very small (Table 31 and Figure 70). The Post-medieval English sample is also significantly smaller compared to the all the previously analysed samples and shows a significant bias towards young females which represent 37% of the sample (Table 32 and Figure 71). These two samples are therefore not comparable among themselves and their asymmetry will have to be taken into account when discussing the parameters that have been studied as Catalan *versus* English samples. See Appendix 4.7 and 4.8 for the specific data regarding the post-medieval English and Catalan individuals.

Table 31: Distribution of the post-medieval English individuals in sex age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	10 (37.0)	3 (11.1)	3 (11.1)	2 (7.4)	18 (66.7)
Males	0 (0.0)	1 (3.7)	5 (18.5)	1 (3.7)	7 (25.9)
Indeterminate	1 (3.7)	0 (0.0)	0 (0.0)	1 (3.7)	2 (7.4)
TOTAL	11 (40.7)	4 (14.8)	8 (29.6)	4 (14.8)	27

Table 32: Distribution of the post-medieval Catalan individuals in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Males	1 (16.7)	0 (0.0)	4 (66.7)	0 (0.0)	5 (83.3)
Indeterminate	0 (0.0)	0 (0.0)	1 (16.7)	0 (0.0)	1 (16.7)
TOTAL	1 (16.7)	0 (0.0)	5 (83.3)	0 (0.0)	6

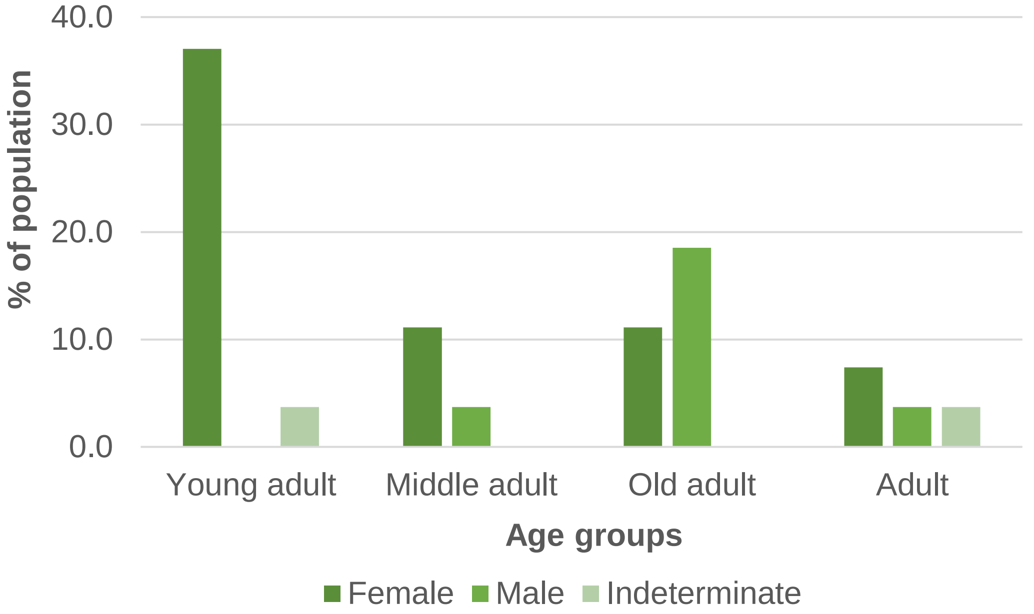


Figure 70: Demographic profile of the Post-medieval individuals from England (n=27)

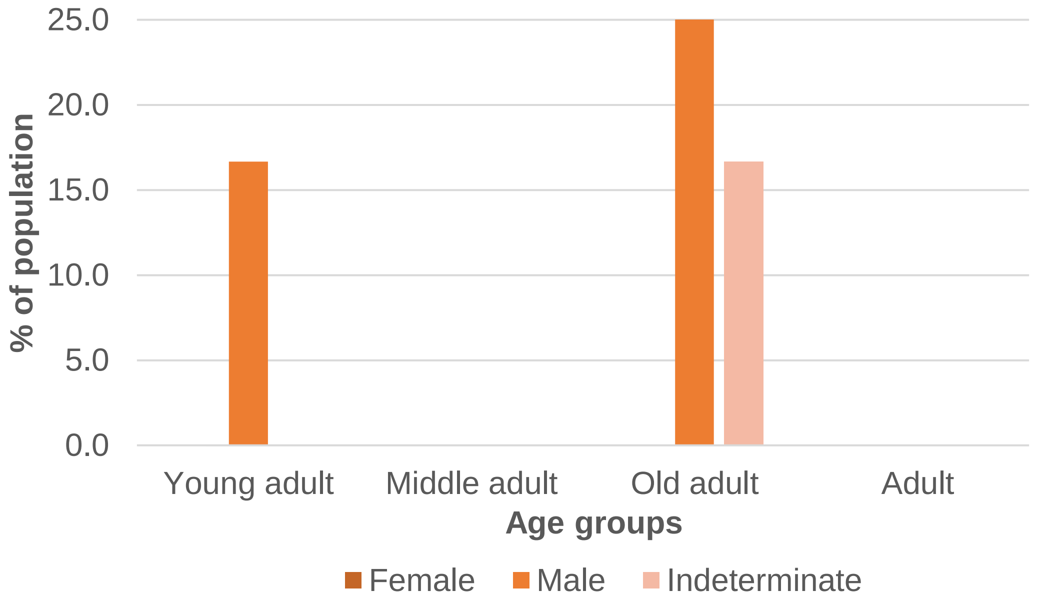


Figure 71: Demographic profile of the Post-medieval individuals from Catalonia (n=6)

B.5.1.5 Combined Catalan and English samples per regions

In some instances, the English and Catalan samples have been combined together per region thus not taking into account the individual chronologies. To evaluate whether these combined samples are comparable, all the data has been combined and summarised in Tables 33 and 34 and Figures 72 and 73.

Table 33: Distribution of the English samples in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	54 (19.2)	29 (10.3)	44 (15.7)	22 (7.8)	149 (53.0)
Males	37 (13.2)	13 (4.6)	53 (18.9)	10 (3.6)	113 (40.2)
Indeterminate	8 (2.8)	2 (0.7)	3 (1.1)	6 (2.1)	19 (6.8)
TOTAL	99 (35.2)	44 (15.7)	100 (35.6)	38 (13.5)	281

Table 34: Distribution of the Catalan sample in sex and age categories (%)

	Young Adult	Middle Adult	Old adult	Adult	TOTAL
Female	33 (13.4)	19 (7.7)	35 (14.2)	18 (7.3)	105 (42.5)
Males	30 (12.1)	8 (3.2)	49 (19.8)	13 (5.3)	100 (40.5)
Indeterminate	6 (2.4)	5 (2.0)	13 (5.3)	18 (7.3)	42 (17.0)
TOTAL	69 (27.9)	32 (13.0)	97 (39.3)	49 (19.8)	247

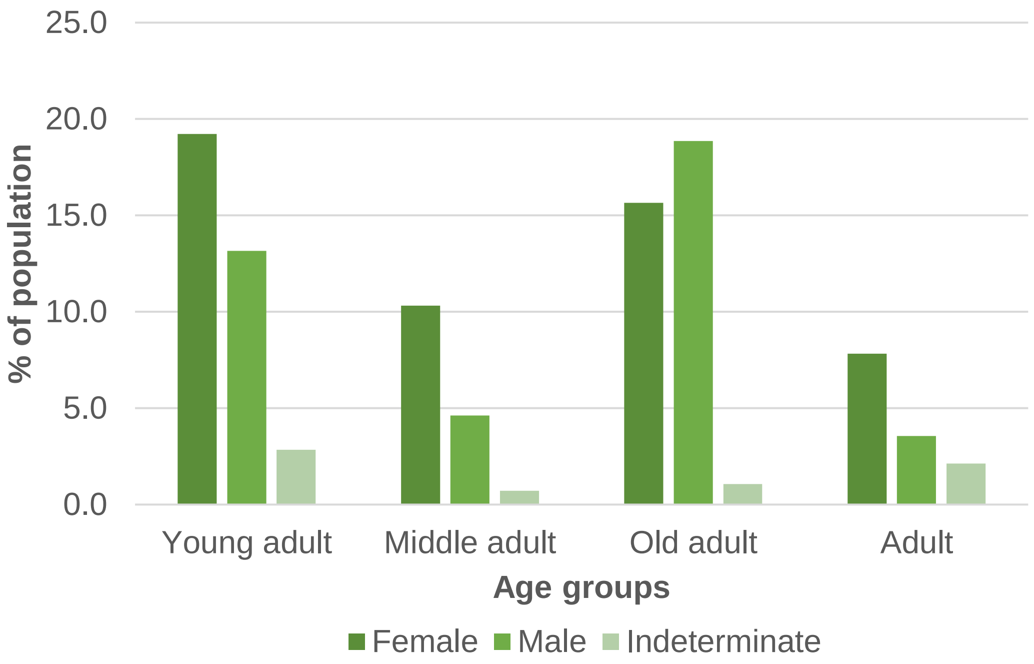


Figure 72: Demographic profile of the combined English samples (n=281)

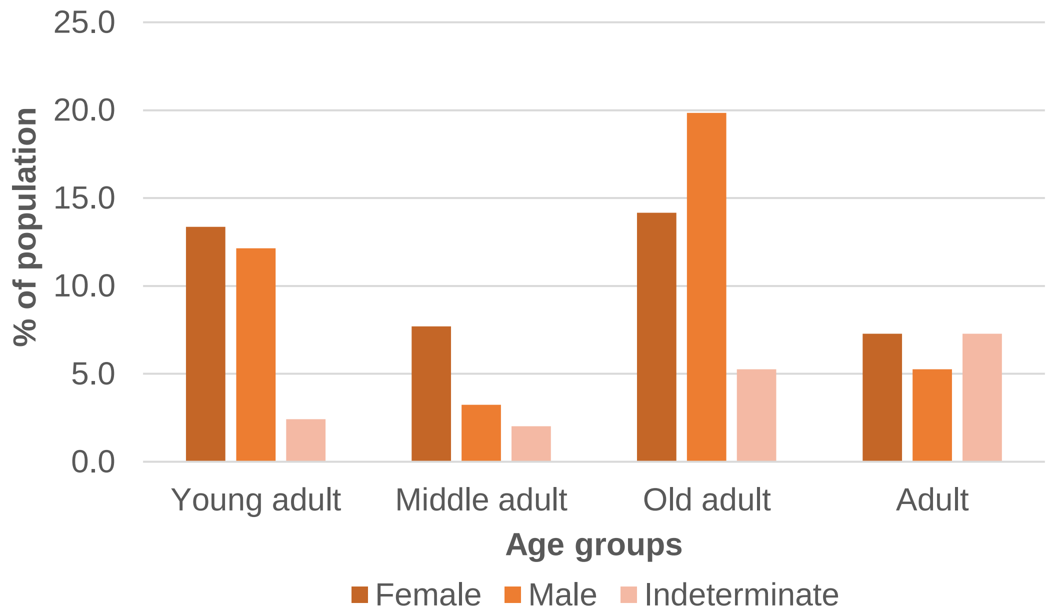


Figure 73: Demographic profile of the combined Catalan samples (n=247)

The demographic profile observed in the combined Catalan and English samples replicate the profiles observed in the Roman, the early medieval and the late medieval Catalan samples with a high prevalence of young and old individuals and a lower presence of middle-age adults (Figures 72 and 73). The statistical analysis, once the individuals classified as *adults* have been removed, also indicate that the age profile of both samples is not significantly different (Independent samples Kruskal-Wallis test, p=0.113) and the Chi-squared test also indicated that the sex distribution of the Catalan and the English samples showed similar distributions (X^2=1.610; p=0.205). These results suggest that the total English and Catalan samples are directly comparable.

B.5.2 Cases of DISH in English samples and evaluation of the prevalence of DISH through time

This section will only be looking to the demographic distribution of the individuals with DISH in each one of the English samples with the same aim of identifying chronological trends within this geographical regions.

In the Romano-British samples of Baldock, Gambier Parry Lodge and Kingsholm seven individuals with DISH were found, representing a prevalence rate of 9.5%. Considering only the individuals whose age could be estimated (see Table 25 for the age distribution in this sample), two middle adult and five old adult individuals were diagnosed with DISH, representing a 2.0% and 16.7% respectively. Of those individuals whose sex could be assessed (36 females and 31 males) only one individual with DISH was assessed as female (2.8%) while the remaining six were found to be male (19.4%). Looking at the stages of the condition represented in this sample, there was one individual showing DISH-related lesions classified as stage 1, stage 2 was observed in three individuals and a further three individuals showed stage 3 lesions. In the total of the sample (n=74) these values represent a prevalence of 1.4% for stage 1 and of 4.1% for stages 2 and 3 each (Figure 74 and Table 35).

Individual GPL525 was considered stage 4 (Table 35) because while only one bridge was clearly observed, there were several very closely interlocking lesions that seem to have started ankylosing at the time of death. This individual also shows a DISH lesion better described as two body-anchored vertical outgrowths both interlocking with a third floating bone outgrowth placed in between.

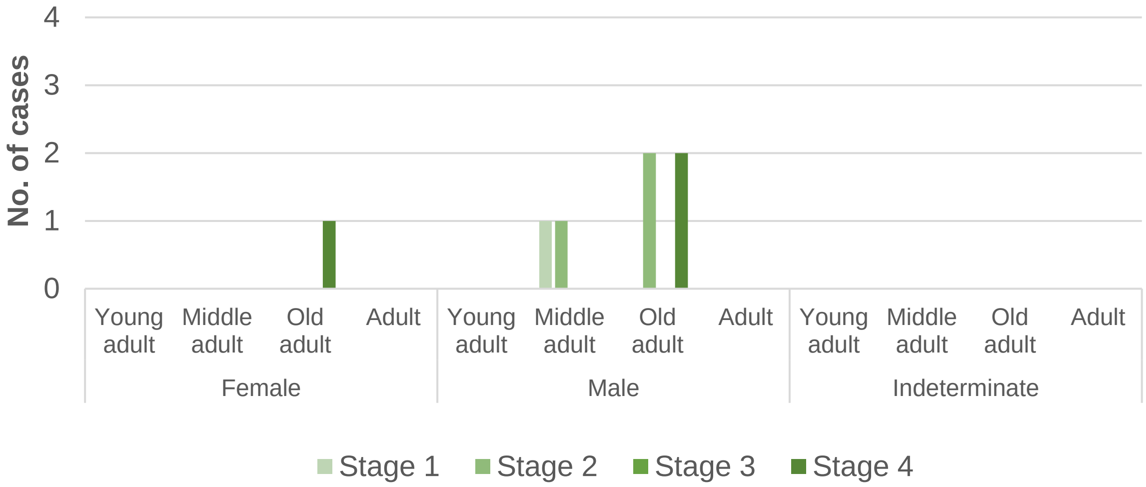


Figure 74: Characterisation of the cases of DISH in the Romano-British sample

The 19 individuals from Anglo-Saxon sample of Raunds represent an overall prevalence of DISH of 16.4%, almost a two-fold increase compared to the previous Romano-British sample (9.5%). In this sample, both sexes and of all age groups affected (Figure 75 and Table 35).

Table 35: Characteristics of the individuals with DISH in the English collections

Period	Site	Ind.	Sex	Age		Vertebrae affected			DISH Stage
				MLE (95%)	Y/M/O	Isolated	Interlocking	Ankylosed	
Romano-British	Baldock	1072	M	47.0 (32.5 – 75.1)	M	L2, L4	-	-	1
	Baldock	1049	M	45.8 (32 – 72.5)	M	-	T8-T12	-	2
	Baldock	1374	M	74.3 (29.1 – 90.8)	O	T8, T10	T5-6, T8-10, L2-3	-	2
	Baldock	2225	M	75.6 (34.6 – 91.4)	O	T10	T12-L1	-	2
	GPL	525	M	76.7 (52.1 – 90.9)	O	L1	T9-10, T11-12. L2-3, L4-5	L3-4	4
	Baldock	F92	M	79.7 (60.6 - 92.2)	O	L3	T7-9	T9-12	4
	Baldock	1122	F	80.0 (61.8 – 92.4)	O	-	C6-7, T1-2, T3-6, T7-10, T11-12	T6-7, T10-11	4
Anglo-Saxon	Raunds	5203	M	35.6 (21.6 – 68.4)	Y	T9, L1, L2	-	-	1
	Raunds	5150	F	36.4 (27.5 – 51.0)	Y	T2, T3, T4	-	-	1
	Raunds	5153	M	74.1 (33.9 – 90.8)	O	L1, L2, L3	L2-3	-	1
	Raunds	5133	M	76.3 (47.3 – 91.0)	O	L1	-	-	1
	Raunds	5045	F	79.6 (60.3 – 92.1)	O	L2	-	-	1
	Raunds	5062	I	A	A	L3	-	-	1
	Raunds	5119	F	A	A	T10, T11	-	-	1
	Raunds	5087	F	33.4 (18.4 – 57.9)	Y	-	T4-6	-	2
	Raunds	5155	M	30.4 (17.0 – 51.4)	Y	L3	T8-9, T9-10, T10-11	-	2
	Raunds	5009	M	35	Y				2
	Raunds	5085	M	37.8 (28.5 – 53.9)	Y	-	L1-3, L3-5	-	2
	Raunds	5118	M	45.5 (31.9 – 72.1)	M	-	T7-10	-	2
	Raunds	5098	M	54.6 (32.4 – 84.6)	M	-	L1-3	-	2
	Raunds	5094a	M	65.1 (38.9 – 84.6)	O	-	T9-11	-	2
	Raunds	5257	F	74.1 (47.4 – 89.6)	O	L1, L2	T7-9, T10-11, L2-3	-	2

Cont…

Table 35 cont…

	Raunds	5120	M	74.8 (44.0 – 90.2)	O	T4, T9, T10, T11, L4, L5	L1-2	-	2
	Raunds	5298	F	79.7 (62.6 – 91.8)	O	-	T8-10	-	2
	Raunds	5186	M	84.2 (68.5 – 110)	O	-	T8-11	-	2
	Raunds	5282	M	68.5 (41.8 – 86.1)	O	T3, L2	T5-11	T10-11	3
Late medieval	YFH	149	F	37.5 (20.4 – 66.7)	Y	L1	-	-	1
	YFH	84	F	50.4 (32.4 – 74.3)	M	-	T6-10	-	2
	YFH	172	M	29.2 (29.2 – 59.0)	Y	L2	T8-11	-	2
	YFH	62	M	81.5 (60.7 – 93.7)	O	-	C6-7, T6-7, T7-10	-	2
	YFH	92	I	A	A	-	T6-12	-	2
	YFH	28	M	37.5 (28.9 – 52.0)	Y	-	C6-7, C7-T1, T11-12, L4-5	C6-7, T7-11, T12-L4, L4-5	4
	YFH	120	M	72.6 (43.3 – 89.1)	O	T9, L4	L3-4	T11-12, L4-S1	4
	YFH	308	F	66.4 (42.7 – 84.2)	O	L2, L3	T7-8, T11-12	T6-7, T8-11	4
Post-Medieval	HB	36	M	73.5 (51.5 – 88.2)	O	L4	-	-	1
	HB	39	F	73.3 (41.4 – 90.1)	O	L1, L5	T11-12	T8-11	4

Sites: GPL: Gambier Parry Lodge; YFH: York Fishergate House; HB: Wolverhampton. Sex categories: M: male, F: female, I: indeterminate. Age categories: Y: young adult, M: middle adult; O: old adult. Vertebrae: C: cervical, T: thoracic, L: lumbar

Considering only the individuals whose age could be estimated (see table 27 for the age distribution in this sample), there were six young-adults, two middle-adults and nine old-adults diagnosed with DISH, representing a 15%, 12.5% and 23.1% of each age group respectively. Of those individuals whose sex could be assessed (61 females and 47 males), six females (9.8%) and 13 males (27.6%) were diagnosed with the disease. Seven cases were classified as DISH in stage 1, stage 2 was observed in 11 individuals and there was one individual in stage 3 (Figure 75). In the total sample (n=116) these values represent a prevalence of 6.0% for stage 1, 9.5% for stage 2 and 0.9% for stage 3.

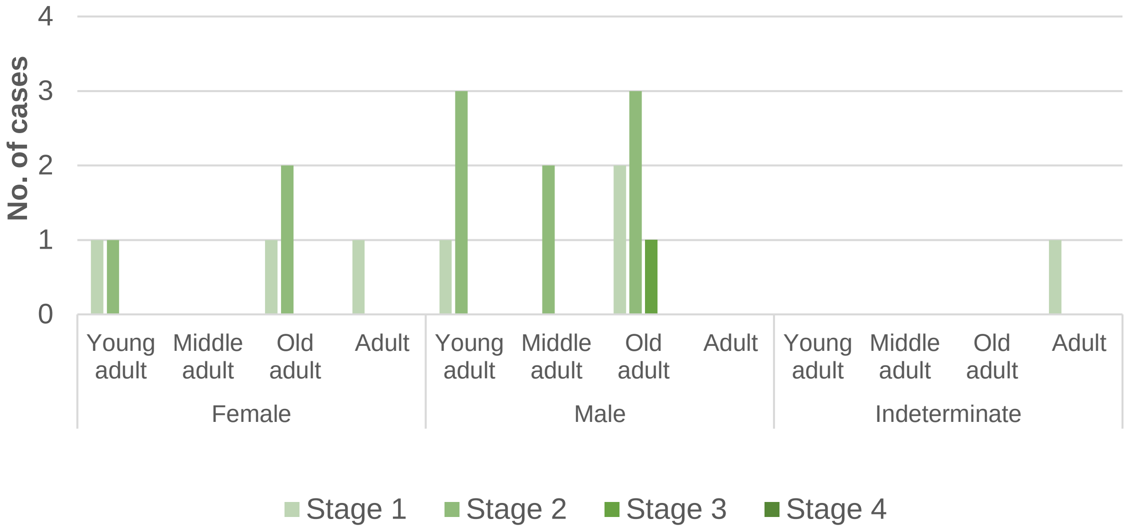


Figure 75: Characterisation of the cases of DISH in the Anglo-Saxon sample

With eight positive diagnosis of DISH (12.5%) in the late medieval sample of York Fishergate House, this is a significant decrease in the prevalence of DISH observed in the Anglo-Saxon sample (16.4%) but still higher than that observed in the Romano-British sample (9.5%).

Considering only the individuals whose age could be estimated (see table 29 for the age-distribution of this sample), there were three young, one middle and three old adult individuals diagnosed with DISH, thus representing a 15% of the young adults, 7.1% of the middle adults and 13% of the old adults. Of those individuals whose sex could be assessed (34 females and 28 males), three females (8.8%) and four males were diagnosed with the disease (14.3%). In this sample (n=64), there was one case of stage 1, four of stage 2 and three of stage 4 representing a prevalence of 1.5% for stage 1, 6.3% for stages 2 and 4.7% for stage 4 (Figure 76 and Table 35).

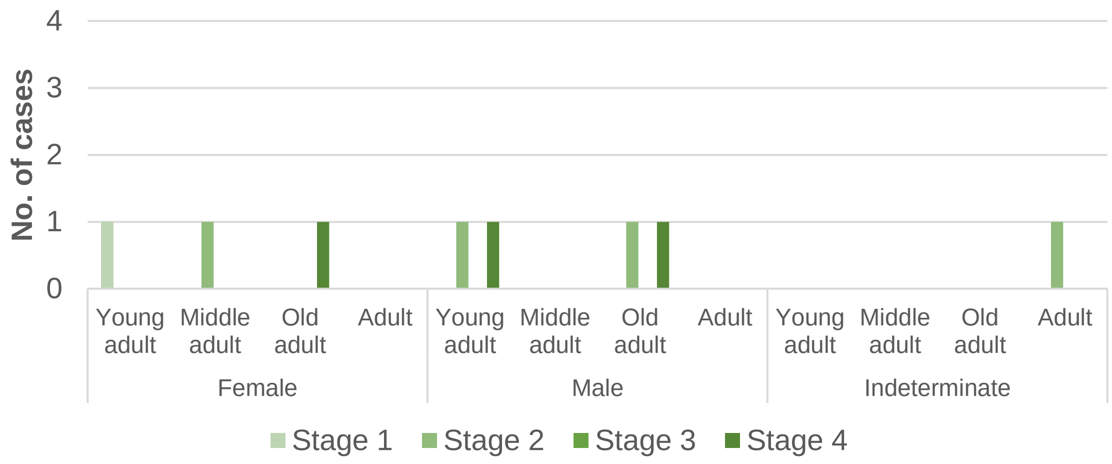


Figure 76: Characterisation of the cases of DISH in the late medieval English sample

Finally, the post-medieval sample of Wolverhampton was significantly smaller than the previous ones therefore any comparison about the prevalence and distribution of the cases of DISH should be attempted with extreme caution.

Nevertheless, of only the individuals whose age could be estimated are considered (see table 31 for the age distribution in this sample) only two old adult individuals showed signs of DISH; this represents a 25% of the old adult sample being affected by the condition. Of those individuals whose sex could be assessed (18 females and seven males), one female (5.5%) and one male (14.3%) were diagnosed with the disease. In this sample, there was one case of stage 1 (3.7%) and one case of stage 4 (3.7%) in the total of the sample (n=27). The total prevalence of DISH in the post-medieval sample of Wolverhampton is of 7.4%, the lowest prevalence found in England (Figure 77 and Table 35).

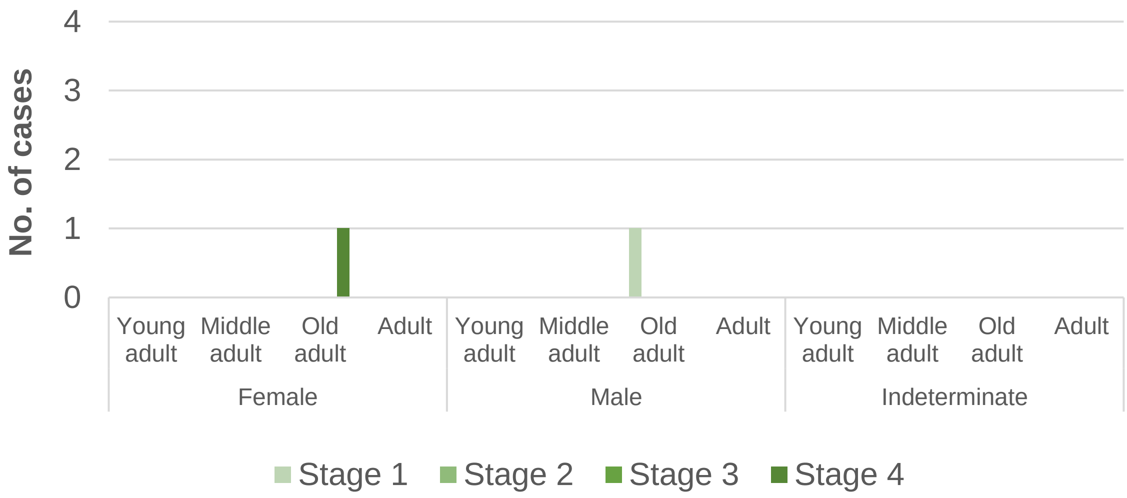


Figure 77: Characterisation of the cases of DISH in the post-medieval English sample

The overall prevalence of DISH in the English sample is 12.8%. Figure 78 summarises the distribution of the cases of DISH in the English samples. Despite the number of males analysed being slightly smaller than the number of females (113 and 149 respectively), in the English samples the prevalence of DISH in the male is significantly higher than in the females (20.4% and 7.4% respectively)

(Figure 78). This suggests that even when being able to identify the earlier stages of the disease, in these samples, DISH is still more prevalent in males than in females. In both sexes, all stages of development of DISH are represented and, as expected, there is a higher number of cases in the older adult group however it is significant that there are three young females and six young males with signs of DISH. Also, as expected, there seems to be a relationship between age and stage of DISH development; with the exception of one young male showing DISH in stage 4 of development, the young individuals show mostly the early stages of the disease while all stages of the disease can be found in the old adult age group (Figure 78). This could possibly indicate that the onset of the disease is not set but varies depending on each individual.

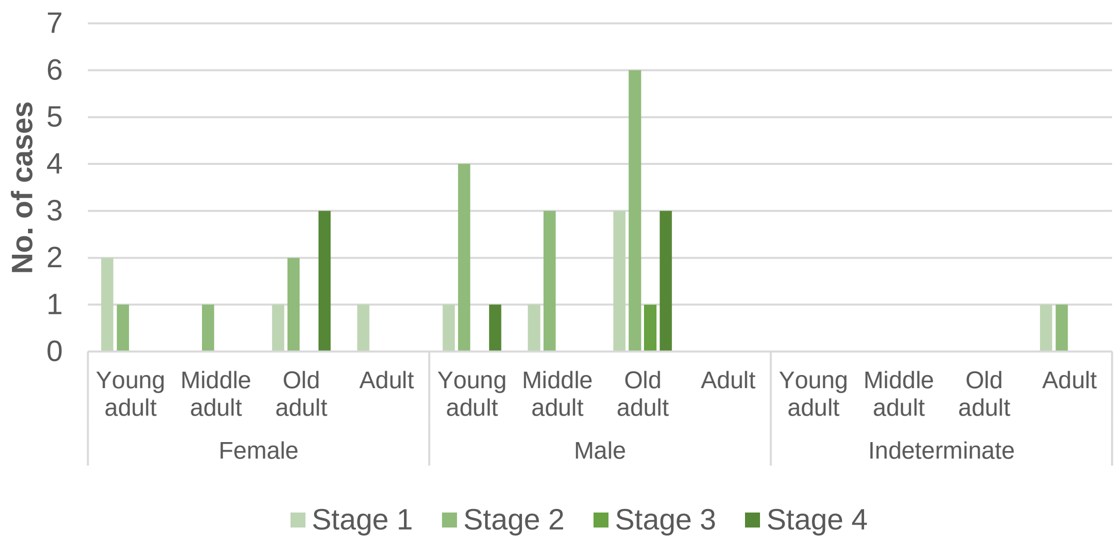


Figure 78: Summary of the demographic distribution of the cases of DISH in the English samples

B.5.3 Cases of DISH in Catalan samples and evaluation of the prevalence of DISH through time

Similarly to the analysis done for the English samples, in this section only the demographic distribution of the individuals with DISH in each one of the Catalan samples will be analysed with the aim of identifying chronological trends within this geographical regions.

In the Roman Catalan samples of Tarraco and Santa Caterina, six individuals with DISH were found, representing an overall prevalence of DISH in the Roman Catalan sample of 6.9%. Age could only be estimated in five of them; one middle and four old individuals, representing a 9.1% and a 12.5% of their respective age groups (see table 26 for the age distribution of this sample). Of a total of 35 females and 36 males individuals whose sex could be assessed, two females (5.7%) and four males (11.1%) showed signs of DISH. In all cases, DISH was present in the earliest of the stages as isolated lesions (stage 1) in three individuals and interlocking or touching outgrowths (stage 2) were observed in three further individuals representing a prevalence of 3.4% for each stage (Table 36 and Figure 79).

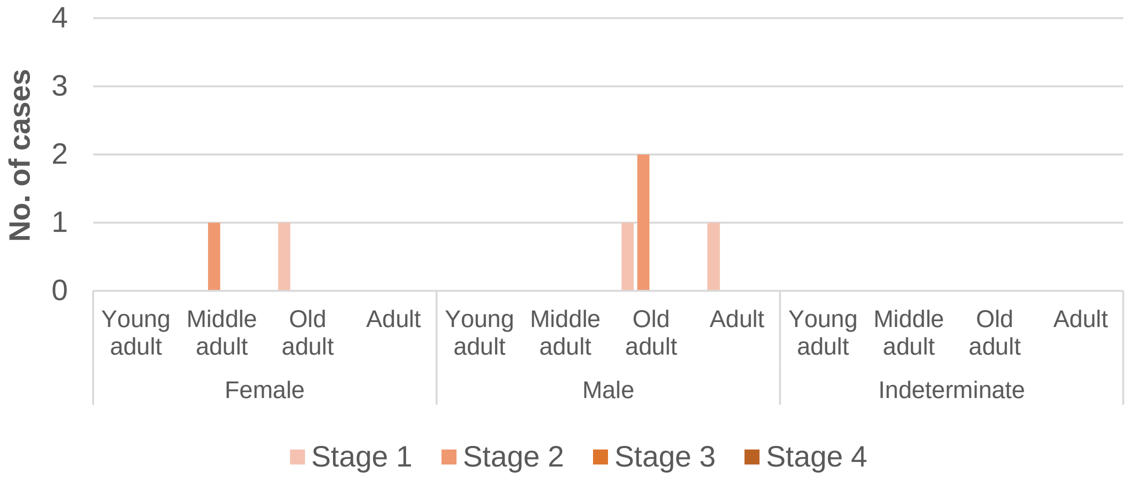


Figure 79: Characterisation of the cases of DISH in the Roman Catalan sample

There are eight cases of DISH in the early medieval Catalan sample of Sant Pere de Terrassa which represent an overall prevalence of DISH in the early medieval Catalan sample of 12.3%; doubling the prevalence from the previous Roman Catalan period (Figure 80 and Table 36). Of the individuals whose age could be estimated (see Table 28 for the age distribution in this sample), three young adults (12%), one middle adult (11.1%) and four old adults (16.7%) suffered from DISH and of the individuals whose sex could be assessed (31 females and 29 males), two females (6.5%) and four males (13.8%) were positively diagnosed with DISH. Regarding the stages of DISH represented, four individuals showed stage 1, stage 2 was observed in two individuals, one individual in stage 3 and another stage 4 lesions. In the total of the sample (n=65) these values represent a prevalence of 6.1%, 3.1% for stages 1 and 2 respectively and of 1.5% for stages 3 and 4.

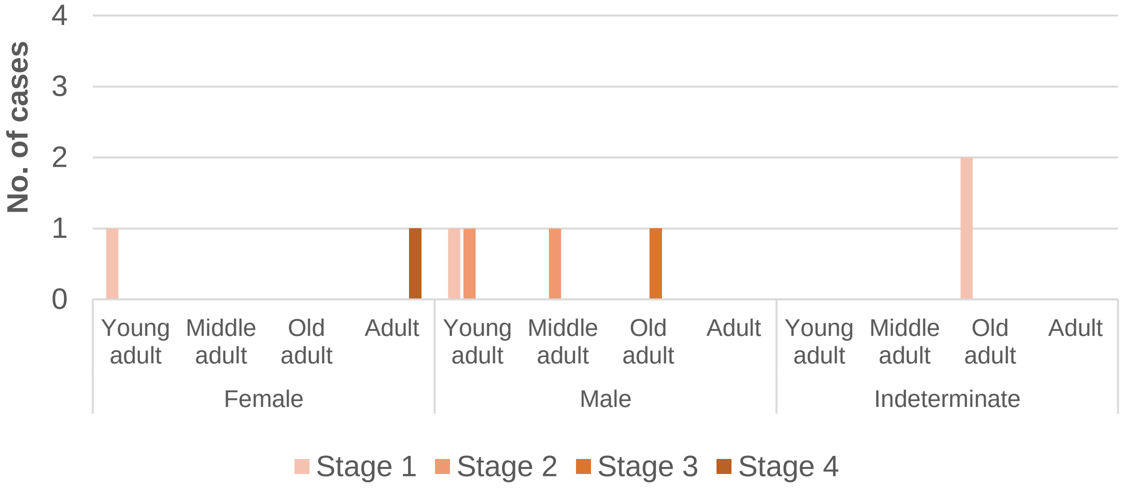


Figure 80: Characterisation of the cases of DISH in the early medieval Catalan sample

Table 36: Characteristics of the individuals with DISH in the Catalan collections

Period	Site	Ind.	Sex	Age		Vertebrae affected			DISH Stage
				MLE (95%)	Y/M/O	Isolated	Interlocking	Ankylosed	
Roman	SC	001-01-754	F	77.0 (21.6 – 110)	O	T1	-	-	1
	SC	002-00-727	M	75.6 (54.5 – 89.6)	O	T7	-	-	1
	Tarraco	1726	M	A	A	L3, L4	-	-	1
	SC	201-05-UF19	F	50.8 (25.3 – 81.3)	M	-	L3-4	-	2
	Tarraco	2192	M	66.2 (30.5 – 87.4)	O	-	T10-11	-	2
	SC	001-01-756	M	72.8 (44.9 – 88.9)	O	-	T7-8	-	2
Early medieval	Terrassa	6	M	20.1 (15.1 – 25.0)	Y	L4	-	-	1
	Terrassa	670	F	33.3 (24.9 – 48.0)	Y	C3, C4, C5	-	-	1
	Terrassa	774	I	71.2 (71.2 – 90.1)	O	T11	-	-	1
	Terrassa	365	M	34.5 (27.3 – 44.9)	Y	-	T8-9	-	2
	Terrassa	658	M	40 (30.5 – 55.3)	M	-	L1-2	-	2
	Terrassa	697	I	70.7 (38.6 – 89.0)	O	T6?	T11-12	-	2
	Terrassa	713	M	72.3 (34.6 – 89.9)	O	T6	T7-T10, L2-3, L3-4	L4-5	3
	Terrassa	480	F	80.9 (65.6 – 92.3)	O	T9, L3	T6-7, T8-9	T5-6, T6-7	4
Late medieval	Canapost	274	M	79.7 (57.5 – 92.6)	O	L3	-	-	1
	Terrassa	288	I	A	A	L3	-	-	1
	Olèrdola	68	M	77.0 (21.6 – 110)	O	-	T9-10, T11-12	-	2
	Terrassa	632	M	78.0 (55.7 – 91.5)	O	T11, L1	L2-4	-	2
	Terrassa	619	M	78.7 (56.3 – 91.9)	O	L5	T11-L1	-	2
	Canapost	279	M	23	Y	-	-	L2-3	3
	Vila-sacra	99	I	53.5 (33.3 – 78.9)	M	-	T9-10	T8-9	3
	Vila-sacra	66	F	68.3	O	-	-	T12-L1	3

Sites: SC: Santa Caterina; Terrassa: Sant Pere de Terrassa; Olèrdola: Sant Miquel d'Olèrdola; Canapost: Sant Esteve de Canapost. Sex categories: M: male, F: female, I: indeterminate. Age categories: Y: young adult, M: middle adult; O: old adult. Vertebrae: C: cervical, T: thoracic, L: lumbar

In the combined late medieval Catalan samples of Sant Esteve de Canapost, Sant Miquel d'Olèrdola, Sant Pere de Terrassa and Vila-Sacra, there are eight cases of DISH. This represents an overall prevalence of 9.0%; a slight decrease compared to the previous early medieval sample (12.3%) while still being higher than the observed in the Roman Catalan sample (6.9%).

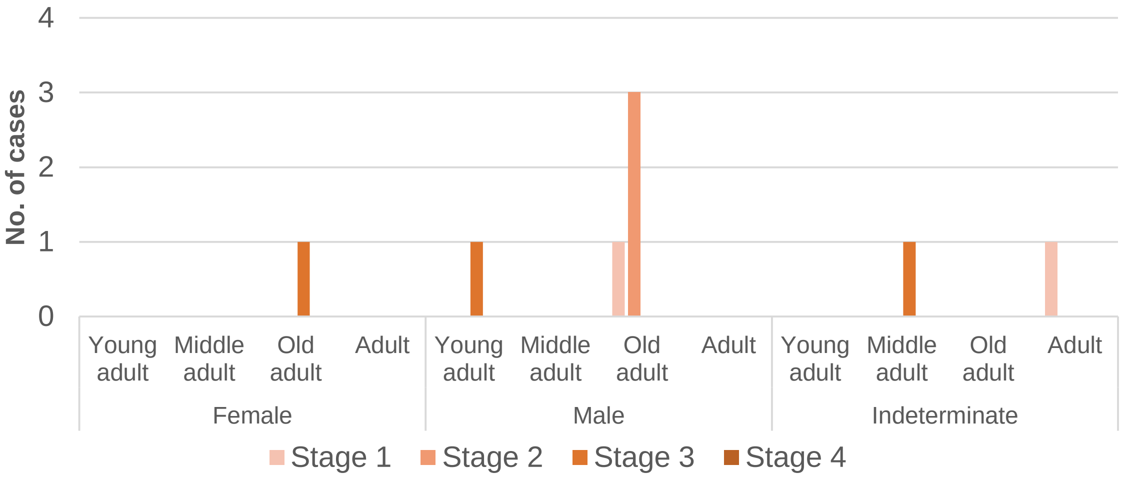


Figure 81: Characterisation of the cases of DISH in the late medieval Catalan sample

Of the individuals whose age could be estimated (see table 28 for the age distribution in this sample), six were diagnosed with DISH: one young adult (5%), one middle adult (8.3%) and four old adults (11.1%). And of the individuals whose sex could be assessed (39 females and 30 males), one female (2.6%) and five males (16.7%) were diagnosed with the disease. Looking at the stages of development represented, stage 1 was identified in two individuals, stage 2 in three and stage 3 also in three individuals (Table 36 and Figure 81). In the total of the sample (n=89) these values represent a prevalence of 2.2% for stage 1 and of 3.4% for stages 2 and 3.

Due to the absence of cases of DISH in the post-medieval Catalan sample, no further analysis on the prevalence of DISH will be carried out with this sample. However to finally investigate whether males and females show a different pattern of DISH development, the following Figure 82 represents the combination of the three previous graphs.

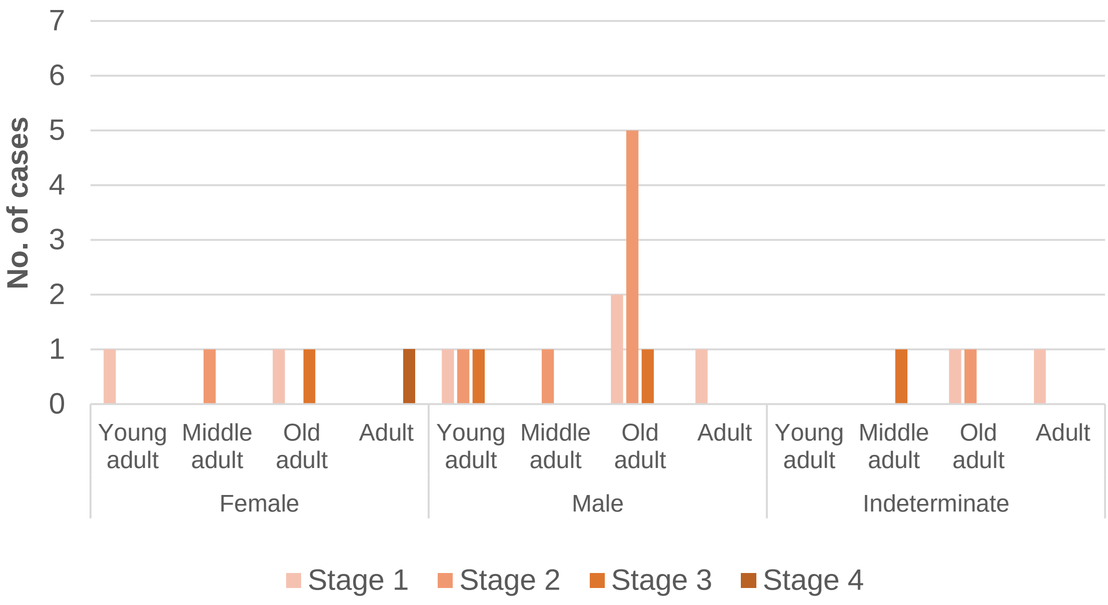


Figure 82: Summary of the demographic distribution of the cases of DISH in the Catalan samples

The overall prevalence of DISH in the Catalan sample is 8.9%, notably lower than the prevalence found in the English sample. It is worth noting that while the combined number of females in the Catalan samples is similar than males (105 and 100 respectively), the number of cases of DISH is significantly higher in males than in females (13% and 4.8% respectively). This suggests that even when it is possible to identify the early stages of DISH development, male individuals in this sample seem to show a greater predisposition to suffer this condition (Figure 82). Due to the small number of cases of DISH in the female sample, it is not possible to evaluate the relationship between stages of development of DISH and age groups. For the male individual with DISH, with the exception of one young individual showing stage 3 lesions, the young and middle adult tend to show the earlier stages of the disease while any stage of the disease can be observed in the older individuals suggesting that, in this sample, the onset of the disease can possibly happen at any point during the individual's lifetime (Figure 82).

B.5.4 Regional comparative analysis of the relationship between DISH and age and sex

In this section, a comparative analysis of the demography of the cases of DISH in England and Catalonia. The aim of this section is to investigate if the demographic profile of the individuals with DISH varies between England and Catalonia. First, the relationship between DISH and age and then the relationship between DISH and sex will be evaluated. Because the sample size of the post-medieval Catalan sample was too small to be comparable to the post-medieval English one, only the Roman, early and late medieval periods will be explored. The supporting tables showing how the cases of DISH are distributed according the age of the individual and the stage of DISH development can be found in Appendix 4.1.

B.5.4.1 Relationship between age and stages of DISH development: England vs Catalonia

As it was indicated in section B.5.1.1, the statistical analysis indicate that the Roman Catalan and English samples are directly comparable. Figure 83 shows the estimated age of the individuals with DISH in both samples distributed according to the stage of DISH development. In this period, the six cases of DISH in the Catalan sample are pre-DISH (stages 1 and 2) even though most of the individuals were old adults. Contrastingly, in the Romano-British samples, DISH was found in its pre-DISH stages as well as a well-developed spinal ankylosis (stage 4). While the number of cases is still small, the Romano-British cases of DISH seem to indicate a stronger relationship between stage of DISH development and age. As it was noted in the previous section, old adults can show any stage of the disease however only old individuals show the most advanced stages of DISH development.

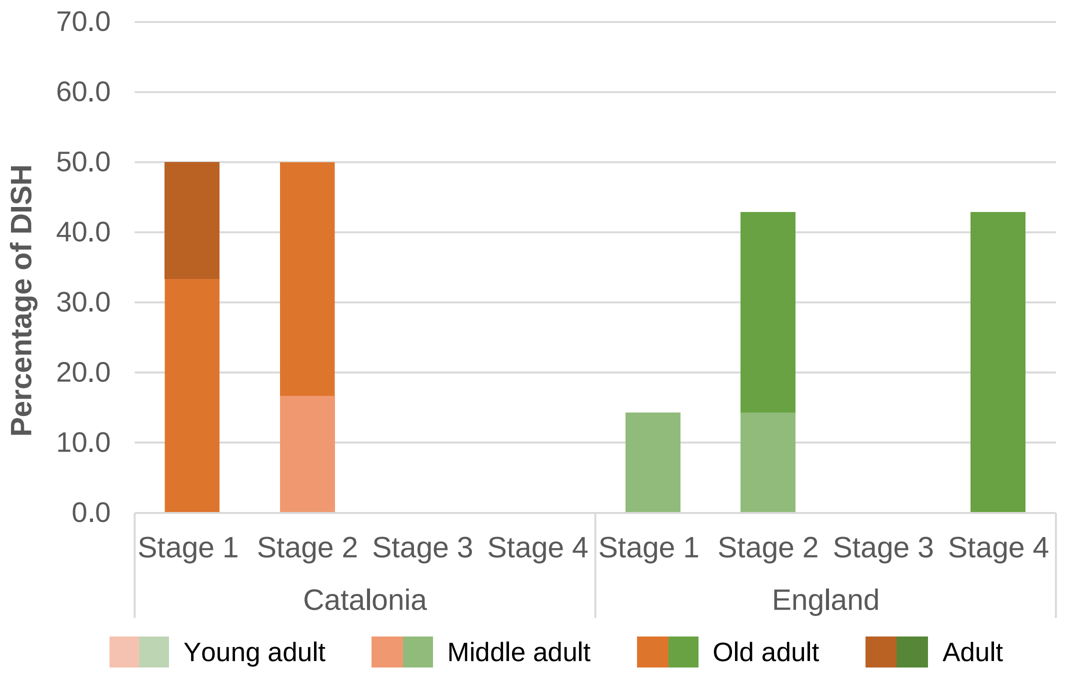


Figure 83: Relationship between age group and stage of DISH development in the Roman Catalan and English samples (%)

Similarly to the Roman samples, the demographic profiles for the early medieval Catalan and English samples are also directly comparable (see section B.5.1.2). The data show that demographic distribution of the cases of DISH in each sample is different (Figure 84). In the Catalan region, all the young and middle adults and 50% of the old individuals (75% of the individuals with DISH) show either stage 1 or 2 of development while only old individuals show the most advances stages of the disease; thus stressing the relationship between age and presence of DISH. In contrast, the Anglo-Saxon individuals of all age groups tend to show only the earlier stages of the disease as only one of the 19 individuals with DISH (5.2%) was classified as stage 3. This trend is very different from the one seen in the Romano-British sample where a clearer age – stage of DISH was observed.

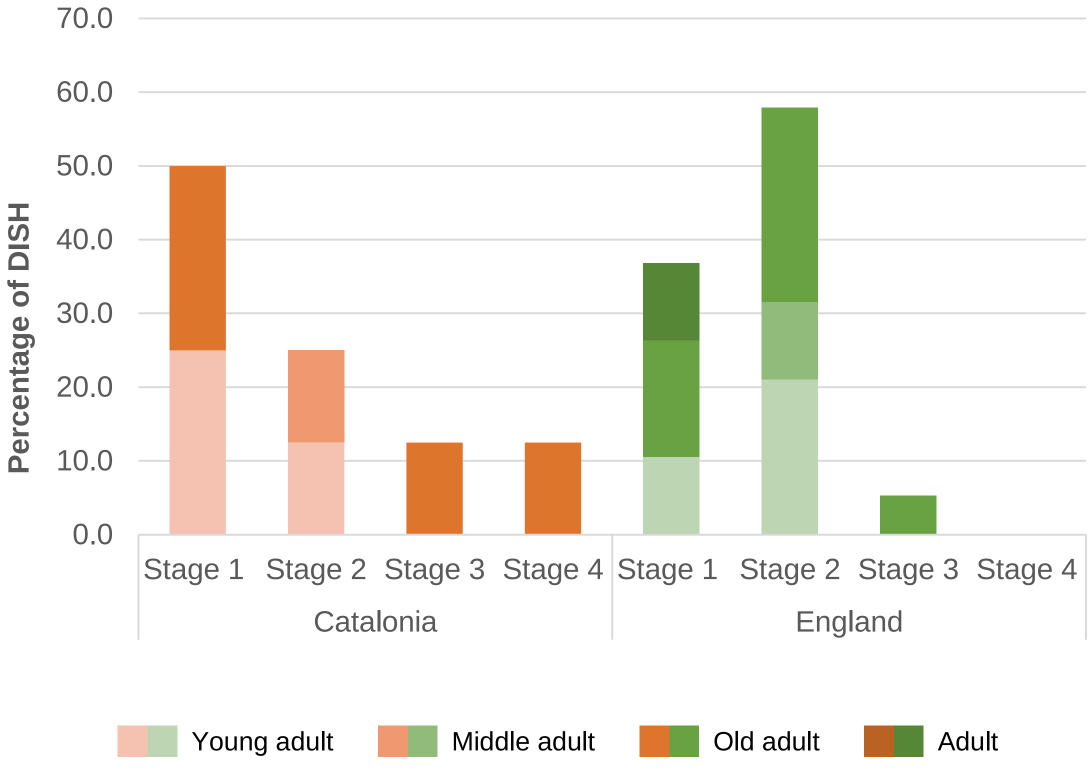


Figure 84: Relationship between age group and stage of DISH development in the early medieval Catalan and English samples (%)

The age distribution of the English and the Catalan late medieval samples is also directly comparable (see section B.5.1.3). While the number of individuals with DISH each sample is the same, their demographic distribution is again slightly different. Almost mimicking the Roman samples, 62.5% of the Catalan individuals with DISH are old adults and, of all cases of DISH observed, almost two-thirds (62.5%) show early stages of DISH while the remaining cases of DISH (37.5%) are individuals with only one bridge completely formed. Meanwhile, the late medieval English individuals have a stronger relationship between age and stage of development as 75% (three out of four) of the young and middle adults showing stages 1 or 2 of DISH and two-thirds of the older individuals showing stage 4 lesions (Figure 85). There are two surprising cases: one young adult from the Catalan sample showing stage 3 lesions and one young adult English individual showing stage 4 lesions. While these cases will be briefly discussed afterward it is possible that these individuals had a stronger predisposition to develop the condition and their life-style might have influenced the early onset of the condition. It is also worth noting that young adult comprises all the individuals between the age of 20 and 40 and, while not abundant, there are reports in the clinical literature referring cases of early onset of DISH (Resnick et al. 1978).

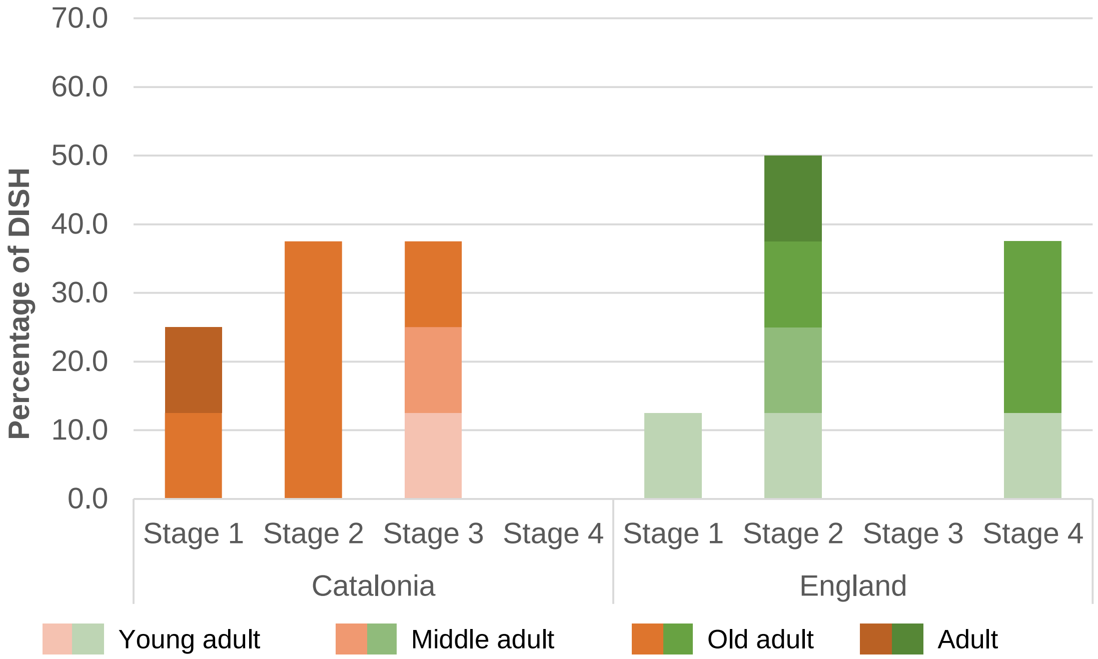


Figure 85: Relationship between age group and stages of DISH development in the late medieval Catalan and English sample

Table 37 summarises the total prevalence of DISH for each age group in the Catalan and English samples. This table also shows how through all time periods, the older segment of the sample seems to show a higher prevalence of the condition. When the significance threshold is set at 0.1, statistical analysis combining English and Catalan samples, suggest that there is no significant correlation between age groups and stage of DISH development (Spearman's Rho Correlation Coef: 0.114; p-value: 0.021). When the regions are considered separately, the lack of correlation between age group and stage of DISH development is maintained in the English (Spearman's Rho Correlation Coef: 0.135; p-value: 0.041) and in the Catalan sample (Spearman's Rho Correlation Coef: 0.108; p-value: 0.153).

Table 37: Relationship between DISH and age in English and Catalan samples (%)

		Age groups		
		Young	**Middle**	**Old**
English populations	Roman	0 (0/18)	2.0 (2/10)	16.7 (5/30)
	Early medieval	15 (6/40)	12.5 (2/16)	23.1 (9/39)
	Late medieval	15 (3/20)	7.7 (1/13)	13 (3/23)
	Post-medieval	0 (0/11)	0 (0/4)	25 (2/8)
Catalan populations	Roman	0 (0/23)	9.1 (1/11)	12.5 (4/32)
	Early medieval	12 (3/25)	11.1 (1/9)	16.7 (4/24)
	Late medieval	0.5 (1/20)	8.3 (1/12)	11.1 (4/36)

The last figure in this series, Figure 86 shows the distribution of the combined cases of DISH in England and in Catalonia. As expected, the majority of the cases of DISH are found in old individuals however it is important to note that 18.1% of the Catalan and 25% of the English cases of DISH were found in young adults (20-40) (Figure 86). This is an important aspect to consider because to evaluate the prevalence of DISH, some studies only include the individuals with an estimated age above 40 or 50 years of age (e.g. Cunha 1993; Kacki and Villotte 2006). This pre-requisite would induce an underestimation of the prevalence of DISH in the target population.

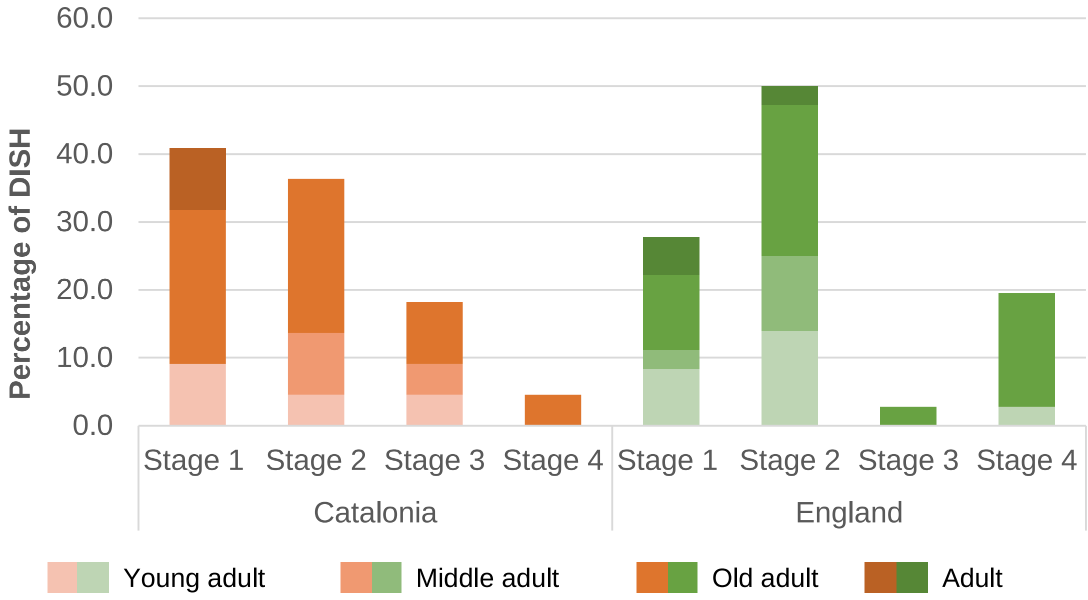


Figure 86: Relationship between age group and stages of DISH development in the combined Catalan and English samples

Figure 86 further highlights the importance of taking into account not only the most advanced stages of DISH (stage 4) but also its earlier stages. 77.3% and 77.8% of the cases of DISH in the Catalan and the English samples, respectively, were classified as stages 1 and 2, and only 22.7% of the Catalan DISH cases and 22.2% of the English DISH cases were of stage 3 and 4. While the diagnosis of early stages of DISH must be done carefully to avoid misdiagnosis and the consequent overestimation of its prevalence, this data suggests that if only the most advanced cases are considered, the prevalence of DISH will be significantly underestimated.

B.5.4.2 Relationship between sex and, DISH status and stages of DISH development: England vs Catalonia

In the previous sections B.5.2 and B.5.3 it was already suggested that, in both regions, male seem to have a stronger predisposition towards developing DISH than females since for all periods and regions the number of males with DISH was systematically higher than that of females (Table 38). Figure 87 demonstrates once more the greater number of males suffering from DISH compared to females. This results are confirmed by the statistical analysis that confirms that the difference in the prevalence of DISH (considered as present or absent) in males and females is statistically significant (X^2 p-value: <0.001).

Table 38: Relationship between DISH and sex in Catalan and English populations

		Sex	
		Female	**Male**
Catalan populations	Roman	5.7 (2/35)	11.1 (4/36)
	Early medieval	6.5 (2/31)	13.8 (4/29)
	Late medieval	5.1 (2/39)	13.3 (4/30)
English populations	Roman	2.8 (1/36)	19.4 (6/31)
	Early medieval	9.8 (6/61)	27.6 (13/47)
	Late medieval	8.8 (3/34)	13 (4/28)
	Post-medieval	5.5 (1/18)	14.3 (1/7)

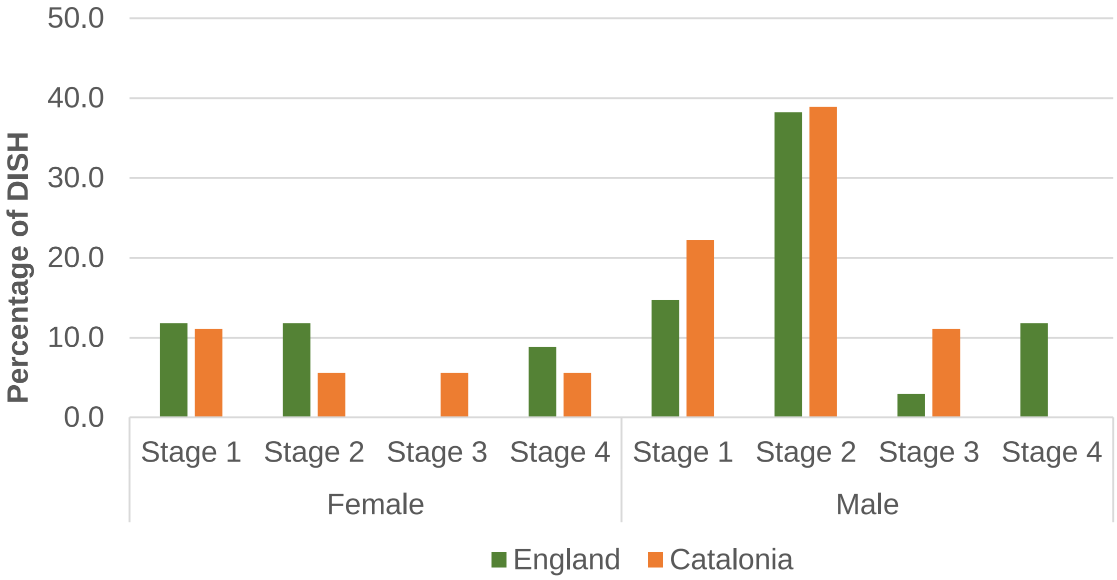


Figure 87: Relationship between sex and stage of DISH development in Catalonia and England

The surprising consistency in the trends of the demographic distribution of DISH in these samples could suggest that some widespread factor is influencing the expression of this condition; be it for example a genetic predisposition or some dietary habit. Thus while with this type of sample and study is not possible to identify the cause of these trends, the different hypotheses will be explored in the following discussion chapter.

B.5.5 Diachronic comparative analysis of the prevalence of DISH in Catalonia and England

In this last section analysing the prevalence of DISH in England and Catalonia will be analysied. It is however worth noting that there is no significant difference in the overall prevalence of DISH in the English and Catalan samples when all the periods are combined (Fisher's exact test p-value: 0.164). It was nevertheless hypothesised, after the study of the dietary changes through time, that the prevalence of DISH would be the highest in the early medieval population, associated to the possibly high meat consumption. The Roman samples were expected to show the lowest prevalence due to their low reliance on meat and fish while late and post-medieval English and Catalan populations are expected to show an intermediate prevalence of DISH associated to the increased consumption of freshwater and marine resources and a decreased consumption in terrestrial fauna (see section B.4 and Appendix 5).

It is therefore important to explore the trends that the prevalence of DISH shows across periods. To facilitate the comparison, in this section, instead of considering the four stages of the condition, we have considered stage 1 and 2 as pre-DISH and stages 3 and 4, as DISH. As this is the first time that the early stages of the DISH have been identified and included in the diagnostic criteria, it was considered that, with this approach, the data would be more easily comparable to other studies. All the data is summarised in Table 39 and represented in Figure 88 for easier visualisation where the early stages of DISH (stage 1 and 2; also referred to as pre-DISH) are represented in the lighter shades and the late stages (stage 3 and 4) are represented in the darker shades of brown for Catalonia or green for England.

Table 39: Cases of pre-DISH (stages 1 and 2) and DISH (stages 3 and 4) in the Catalan and English sample through time considering pre-DISH and DISH stages (%)

	Period	n.	pre-DISH (%)	DISH (%)
England	Romano-British	74	4 (5.4)	3 (4.1)
	Anglo-Saxon	116	17 (14.7)	1 (0.9)
	Late medieval	64	5 (8.2)	3 (4.9)
	Post-medieval	27	1 (3.7)	1 (3.7)
Catalonia	Roman	86	6 (6.9)	0 (0.0)
	Early medieval	65	6 (9.2)	2 (3.1)
	Late medieval	89	5 (5.6)	3 (3.4)
	Post-medieval	6	0 (0.0)	0 (0.0)

In the English sample, there is a variation in the percentage of individuals affected by the disease (evaluated as DISH vs no-DISH individuals) across time however statistical analysis indicate that this variation is not significant (X^2 p-value: 0.369). As highlighted in section B.5.3, the Anglo-Saxon sample has the highest prevalence of DISH, a jump is mainly at the expense more pre-DISH cases although there is also a reduction in the prevalence of the late stages of the disease. The prevalence of DISH in the Romano-British sample is still lower than during the late medieval sample, however this difference is again driven by the prevalence of pre-DISH since in both cases as the percentage of cases in stage 3 and 4 is similar. The prevalence of DISH in the post-medieval English sample of Wolverhampton is the lowest of all however considering the very small sample size, this decrease should be considered with great caution.

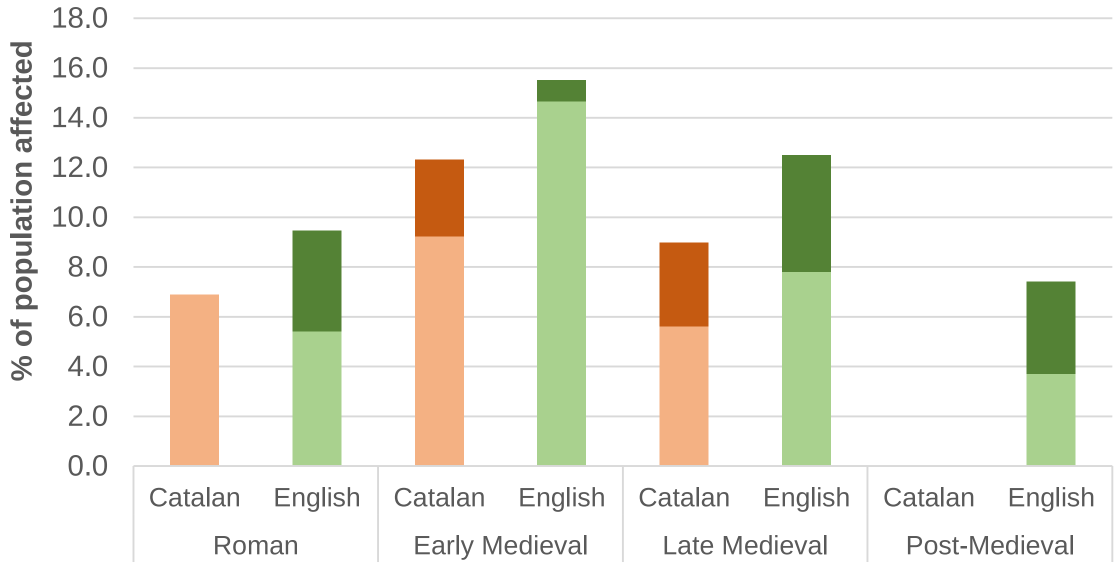


Figure 88: Comparison of the prevalence of DISH in Catalonia and England through time considering pre-DISH (light brown/green) and DISH (dark brown/green) stages (%).

Similar to the trend observed in the English samples, in the Catalan samples, a increase in the prevalence of DISH between the Roman and the early medieval samples (noted in section B.5.2). The difference in the prevalence of DISH between the Roman, the early and the late medieval periods is not significant when evaluated as DISH vs no-DISH individuals (X^2 p-value: 0.518). Nevertheless, Figure 88 suggest an increase in the prevalence of pre-DISH cases in the early medieval sample as well as the identification of stages 3 and 4 which had been absent in the Roman sample. The prevalence of DISH in the late medieval period is slightly lower than in the earlier sample however it still remains higher than in the Roman period. In this last period all phases of the disease are represented.

Comparing the English and the Catalan trends, it is interesting to observe that both regions have very similar chronological trends for the prevalence of DISH. In both cases, the period with the lowest prevalence is the Roman period, both see a surge in the presence of the disease during the early medieval samples which is followed a noticeable decrease in the late medieval samples. In both cases this trend is mainly at the expense of a changing prevalence in the pre-DISH stages as with few exceptions already noted, the prevalence of advanced DISH (stages 3 and 4) remains considerable stable in each region and for all samples. It is however important to notice that these changes are, in fact, trends as the difference in prevalence between the different time periods, when the English and Catalan data are combined, do not show statistically significance difference (X^2 p-value: 0.121). There is also a higher percentage of cases of pre-DISH than DISH.

English samples have consistently higher prevalence of the disease across all time periods; this difference in prevalence is also quite consistent at 2-3% (Figure 88) however it is not statistically significant for any of the periods (Fisher's exact test p-value for: Romano-British vs Roman Catalan: 0.576, Anglo-Saxon vs Catalan early medieval: 0.519, English vs Catalan late medieval: 0.594). Nevertheless, there is a symmetrical trend in the prevalence of DISH in which there is an increase in the early medieval which might suggest that these samples might have been affected by a similar event. Interestingly, the transition of historical period in the England from Romano-British to the early medieval is marked by the arrival of migrants from Northern Europe while in Catalonia, the change from historical periods is triggered by the arrival of the Visigoths from

Central Europe which could have somehow influenced the native population by altering its dietary habits, lifestyle or potentially genetic makeup depending on the scale of the populations change. These hypothesis cannot be tested with the sample available however they will be further explored in the next chapter (B.6 Discussion).

B.5.6 Distribution of the spinal lesions in archaeological human remains

As it has been noted earlier, the lower thoracic and higher lumbar are the areas considered to be most commonly affected by the DISH ankylosis (e.g. Forestier and Lagier 1971; Tsukamoto et al. 1977; Resnick et al. 1978; Cunha 1993) and the results obtained from the analysis of the WM Bass Donated Skeletal Collection (also referred to as the Bass Collection) agreed to this distribution (see section A.3.3). It was thus decided to investigate the distribution of the ankylosis in the archaeological human remain sample, expecting that they would show a similar involvement pattern.

Because all the individuals from the Bass Collection were considered as stage 4 (more than two vertebrae involved in the ankylosis), only the individuals from the Catalan and English samples showing spinal changes at the last stage were considered for this comparison. This constraint resulted in a relatively small archaeological sample of eight individuals being compared to the 44 individuals from the Bass Collection; thus these results should be taken with caution.

Nevertheless, Figure 89 shows the distribution of the ankylosed bridges and interlocking lesions in the modern and the archaeological samples. The interlocking lesions were included in the analysis because they possibly indicate the direction of ankylosis and are those vertebrae that, if the individual had lived longer, would have been involved in the ankylosis.

Table 40: Representation of how often a specific vertebra appears affected in the individuals with stage 4 DISH in historical Catalan and English and in the Bass collection individuals (%)

	Historic (n=8)	Bass Collection (n=44)
T1	0	4.5
T2	0	15.9
T3	0	34.1
T4	0	52.3
T5	12.5	56.8
T6	37.5	70.5
T7	50	79.5
T8	37.5	86.4
T9	50	93.2
T10	62.5	93.2
T11	75	65.9
T12	37.5	40
L1	12.5	20
L2	12.5	<5
L3	25	<5
L4	37.5	<5
L5	25	<5

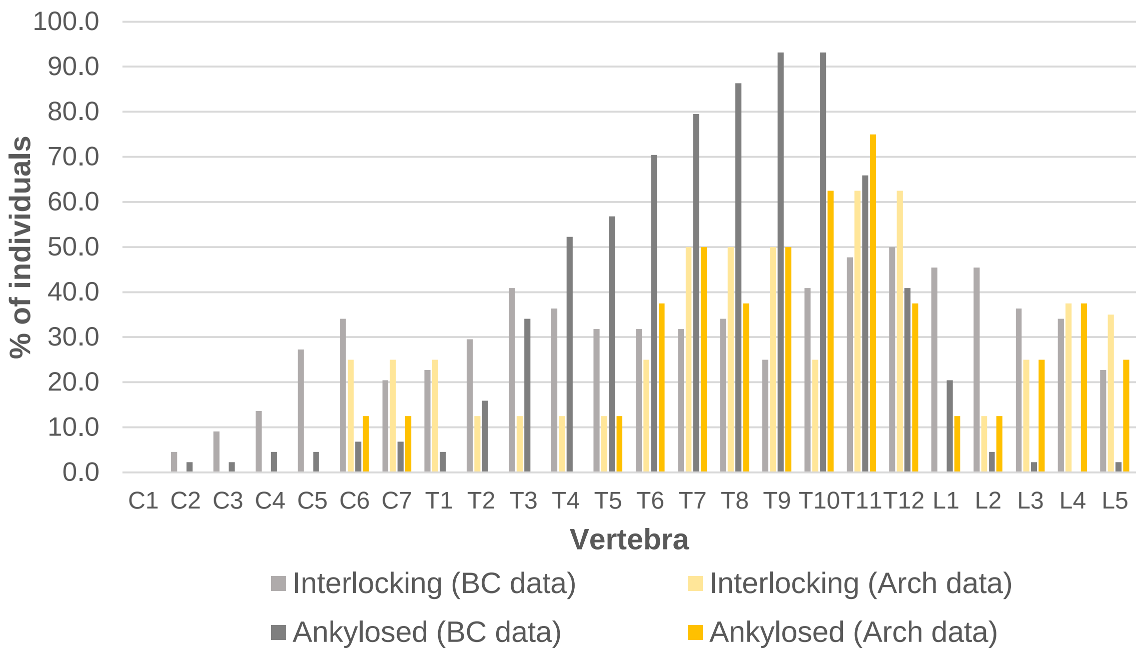


Figure 89: Comparison of the distribution of interlocking lesions and ankylosed bridges between the individuals from the WM Bass Donated Skeletal Collection (BC) and archaeological (Arch) human remains

As it was previously discussed, the vertebrae most usually affected by the ankylosis in the Bass Collection are from T7 to T11, with the adjacent vertebrae being gradually less affected. This suggests that in modern cases DISH is truly concentrated in the lower thoracic section (see section A.4.4 for discussion). In contrast, the most commonly affected vertebrae in the archaeological sample are T11 and T10 (75% and 62.5% respectively), followed by T7 and T9 (both at 50%) and finally T12, T8 and T6 (affected in 37.5% of the individuals). Interestingly, the most evident difference in the distribution of the ankylosis between the two samples is the involvement of the lumbar section (Table 40, Figure 89). In the individuals from the Bass Collection, the involvement of T12 is observed in 40% of the sample while involvement of L1 is seen in only 20% of the individuals and less than 5% show ankylosed bridges in L2, L3 L4 and L5. In contrast, in the archaeological sample 37.5% (3 out of 8) of the individuals show involvement of T12 and L4, 25% (2 out of 8) of L3 and L5.

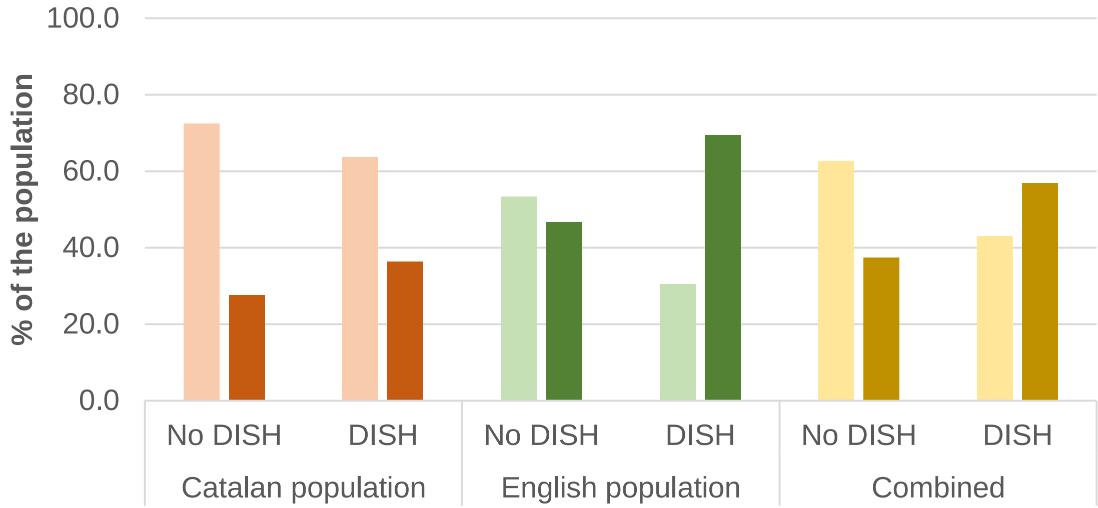
B.5.7 Relationship between DISH and discarthrosis

As it was noted in section A.4.5, the relationship between DISH and discarthrosis is still a topic of discussion. The results obtained from the Bass Collection (section A.3.4) suggested that its co-morbidity was DISH was a usual finding, mainly at the lumbar level.

The study of the prevalence of discarthrosis in the Catalan and the English samples suggest different regional trends as discarthrosis is significantly less common in the former (Table 41 and Figure 90). Furthermore, in the Catalan sample, the majority of the individuals did not suffer from discarthrosis regardless of the individual DISH status. In regards to the English sample, the prevalence of discarthrosis is greater than in the Catalan sample and the percentage of individuals with DISH *and* discarthrosis is significantly higher than the number of individuals with only DISH. For individuals without DISH, the percentage of individuals with and without discarthrosis was very similar.

Table 41: Co-occurrence of DISH and discarthrosis in the Catalan and the English samples

		Catalan sample		English sample		Combined sample	
		No DISH	DISH	No DISH	DISH	No DISH	DISH
Discarth	No	163	14	127	11	290	25
	Yes	62	8	111	25	173	33
	TOTAL	225	22	238	36	463	58



Light shade = No discarthrosis observed. Dark shade = discarthrosis observed

Figure 90: Prevalence of the co-occurrence of DISH and discarthrosis in the Catalan and the English samples (%)

In the third part of the Figure 90, both samples were combined to analyse how the relationship between DISH and discarthrosis was despite the regional differences. The results mimic those obtained from the Bass Collection which suggested that these both conditions can co-exist in the same individual.

B.5.8 Relationship between the spinal and the extra-spinal manifestations of DISH

As it has been noted, DISH has been described as presenting spinal and extra-spinal manifestations. In this context, it was considered that individuals without DISH should show a lower prevalence of ESM compared to that observed in the sub-sample of individuals with DISH. It was also hypothesised that as peripheral enthesopathy is associated to age and activity, individuals without DISH could also develop them but that, in this case, the enthesopathies would be significantly smaller in size when compared to those developed by individuals with DISH.

The study of the relationship between the spinal and the extra-spinal manifestations of DISH in archaeological samples is complicated by the fact that in several cases, the elements were missing or only one side had been recovered. DISH-related extra-spinal enthesopathies are meant to be bilateral/symmetrical (section A.4.6), thus only the cases where both sides were present and observable were included in this analysis. Appendices 4.1 to 4.8 shows all the data regarding the extra-spinal manifestations.

To allow the comparison, the real size of the enthesopathies have been distributed in five groups: smooth to uneven; spicules or enthesophytes up to 1.9mm; 2mm to 4.9mm; 5mm to 9.9mm and over 10mm. By smooth is understood that there were no changes on the entheseal surfaces, by uneven enthesopathy is understood that the entheses showed smooth bevelling on its surface and finally, the spicules are the small crests measuring around 1mm. This distribution by size of the enthesophytes was carried out to facilitate the evaluation of the symmetry/bilaterality of the lesions while allowing a small range of variation between right and left sides.

B.5.8.1 Entheseal changes in the Catalan and the English samples

Tables 42 – 44 summarise the enthesopathic status of the *M. triceps brachii,* the *M. quadriceps femoris* and the insertion of the Achilles tendon, respectively, in the English samples while Tables 45 – 47 summarise them for the Catalan samples. There tables include all individuals, with and without DISH, whose left and right side were observable. In all tables there is a value in bold which indicate the highest percentage in the table and thus most common enthesopathic combination.

Table 42: Characterisation of the enthesopathies at the *M. triceps brachii* insertion in the English sample (%; n=174)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**70.7**	7.5	0.6	0.0	0.0	78.7
	1.0 – 1.9mm	5.7	5.2	1.7	0.0	0.0	12.1
	2.0 – 4.9mm	1.7	2.3	4.0	0.0	0.0	8.6
	5.0 – 9.9mm	0.0	0.0	0.6	0.0	0.0	0.6
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	78.2	14.9	6.9	0.0	0.0	100.0

Table 43: Characterisation of the enthesopathies at the *M. quadriceps femoris* insertion in the English sample (%; n=140)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**49.3**	5.7	2.1	0.7	0.0	57.9
	1.0 – 1.9mm	4.3	15.0	6.4	0.0	0.0	25.7
	2.0 – 4.9mm	2.1	2.1	6.4	0.7	0.7	12.1
	5.0 – 9.9mm	0.0	2.1	1.4	0.7	0.0	4.3
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	55.7	25.0	16.4	2.1	0.7	100.0

Table 44: Characterisation of the enthesopathies at the Achilles tendon insertion in the English sample (%; n=131)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	26.7	3.8	0.8	0.0	0.0	31.3
	1.0 – 1.9mm	6.9	**32.8**	5.3	0.0	0.0	45.0
	2.0 – 4.9mm	0.0	4.6	10.7	3.8	0.0	19.1
	5.0 – 9.9mm	0.0	0.0	3.8	0.8	0.0	4.6
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	33.6	41.2	20.6	4.6	0.0	100.0

In both regions and when the entire sample is taken into account, the most common finding in the *M. triceps brachii* and at the *M. quadriceps femoris* insertions at the olecranon and the patella, respectively, is a smooth or uneven surface without enthesopathic changes. The insertion of the Achilles tendon at the tuberosity of the calcaneus shows slightly more developed enthesopathies in the English sample however these do not commonly exceed the 2mm in size. In the Catalan sample of individuals without DISH, the percentage of individuals showing smooth or uneven entheseal changes is very similar to that showing small enthesophytes of less than 2mm in size. The percentage of individuals showing this pattern changes depending on the site analysed; over two-thirds of the English and Catalan sample show smooth or uneven entheseal changes at the insertion of the *M. triceps brachii* (Tables 42 and 45), just under half of the English individuals and two-thirds of the Catalan sample show symmetric smooth or uneven *M. quadriceps femoris* insertion (Tables 43 and 46). Finally, just under a third of the Catalan and the English sample have symmetric small spicules at the insertion of the Achilles tendon (Tables 44 and 47). This suggest that the enthesopathies at the patella and the calcaneus vary significantly between individuals possibly as a result of age and/or activity.

Table 45: Characterisation of the enthesopathies at the *M. triceps brachii* insertion in the Catalan samples (%; n=108)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**88.0**	1.9	0.0	0.9	0.0	90.7
	1.0 – 1.9mm	0.0	4.6	1.9	0.0	0.0	6.5
	2.0 – 4.9mm	0.9	0.9	0.9	0.0	0.0	2.8
	5.0 – 9.9mm	0.0	0.0	0.0	0.0	0.0	0.0
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	88.9	7.4	2.8	0.9	0.0	100.0

Table 46: Characterisation of the enthesopathies at the *M. quadriceps femoris* insertion in the Catalan samples (%; n=77)

		Right side					
		Smooth -uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**66.2**	10.4	0.0	0.0	0.0	76.6
	1.0 – 1.9mm	2.6	13.0	1.3	0.0	0.0	16.9
	2.0 – 4.9mm	1.3	1.3	2.6	0.0	0.0	5.2
	5.0 – 9.9mm	0.0	0.0	0.0	1.3	0.0	1.3
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	70.1	24.7	3.9	1.3	0.0	100.0

Table 47: Characterisation of the enthesopathies at the Achilles tendon insertion in the Catalan samples (%; n=105)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**32.4**	1.9	1.0	0.0	0.0	35.2
	1.0 – 1.9mm	1.9	31.4	4.8	0.0	0.0	38.1
	2.0 – 4.9mm	0.0	6.7	12.4	3.8	0.0	22.9
	5.0 – 9.9mm	0.0	0.0	1.0	2.9	0.0	3.8
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	34.3	40.0	19.0	6.7	0.0	100.0

Finally, Tables 48 – 50 summarise the characterisation of the lesion when the Catalan and English samples are merged. As seen when both samples were analysed separately, the majority of the individuals, 77.3% and 55.3% show no or very uneven symmetrical entheseal changes at the insertions of the *M. triceps brachii* and the *M. quadriceps femoris,* respectively. The insertion of the Achilles tendon is the enthesis that show bigger changes although the most common finding is lesions between 1.0 and 1.9mm. Following the previous pattern, there seems to be more interpersonal variability in the enthesopathies observed at the calcaneal tuberosity as only a third of the sample show symmetrical spicules-1.9mm lesions.

Table 48: Characterisation of the enthesopathies in at the *M. triceps brachii* insertion in the combined English and Catalan samples (%; n=282)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**77.3**	5.3	0.4	0.4	0.0	83.3
	1.0 – 1.9mm	3.5	5.0	1.8	0.0	0.0	10.3
	2.0 – 4.9mm	1.4	1.8	2.8	0.0	0.0	6.0
	5.0 – 9.9mm	0.0	0.0	0.4	0.0	0.0	0.4
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	82.3	12.1	5.3	0.4	0.0	100.0

Table 49: Characterisation of the enthesopathies in at the *M. quadriceps femoris* insertion in the combined English and Catalan samples (%; n=217)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**55.3**	7.4	1.4	0.5	0.0	64.5
	1.0 – 1.9mm	3.7	14.3	4.6	0.0	0.0	22.6
	2.0 – 4.9mm	1.8	1.8	5.1	0.5	0.5	9.7
	5.0 – 9.9mm	0.0	1.4	0.9	0.9	0.0	3.2
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	60.8	24.9	12.0	1.8	0.5	100.0

Table 50: Characterisation of the enthesopathies in at the Achilles tendon insertion in the combined English and Catalan samples (%; n=236)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	29.2	3.0	0.8	0.0	0.0	33.1
	1.0 – 1.9mm	4.7	**32.2**	5.1	0.0	0.0	41.9
	2.0 – 4.9mm	0.0	5.5	11.4	3.8	0.0	20.8
	5.0 – 9.9mm	0.0	0.0	2.5	1.7	0.0	4.2
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	33.9	40.7	19.9	5.5	0.0	100.0

B.5.8.2 Entheseal changes in the individuals with DISH from the Catalan and the English samples

In this section, the entheseal changes observed in individuals with DISH in the English and the Catalan samples as well as in the combined sample will be analysed. In Appendix 4 (tables 4.3 and 4.4) a summary of the individuals with DISH from Catalonia and England who has at least one entheseal site observable, can be found.

The English sample shows slightly different pattern to what has been seen until now although these results must be read with caution because of the small sample size. Nevertheless, the group of English individuals with DISH, the most common finding at the *M. triceps brachii* insertions is a minimal entheseal change (48.0%, Table 51). This represents a significant increase compared to the original sample (Table 42) as just over half of the sample do show some kind of enthesopathy. The insertion of the *M. quadriceps femoris* at the patella show, in equal prevalence, either no entheseal changes or enthesophytes ranging from 5 to 9.9mm in size (Table 52). The prevalence of these types of enthesopathies are, however, significantly low (17.9%) suggesting that this entheseal site shows an even higher range of variability than the previously reported for this site. Finally, the insertion of the Achilles tendon of the English individuals with DISH is the only one in the series that shows a higher prevalence of bilateral but not symmetrical enthesopathies (Table 53). In this subsample, 23% of the individuals show a right Achilles tendon enthesis more developed than the left. While this result is unexpected, the table shows that, in fact, the majority of the sample (51.7%) do show symmetrical entheseal changes however the high interpersonal variation possibly results in the reduction of each individual symmetrical range.

Table 51: Characterisation of the enthesopathies at the *M. triceps brachii* insertion in the English individuals with DISH (%; n=25)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**48.0**	4.0	0.0	8.0	0.0	60.0
	1.0 – 1.9mm	4.0	16.0	12.0	4.0	0.0	36.0
	2.0 – 4.9mm	0.0	0.0	0.0	0.0	0.0	0.0
	5.0 – 9.9mm	0.0	0.0	0.0	4.0	0.0	4.0
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	52.0	20.0	12.0	16.0	0.0	**100.0**

Table 52: Characterisation of the enthesopathies at the *M. quadriceps femoris* insertion in the English individuals with DISH (%; n=23)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**17.4**	8.7	0.0	0.0	0.0	26.1
	1.0 – 1.9mm	4.3	13.0	4.3	4.3	0.0	26.1
	2.0 – 4.9mm	0.0	13.0	4.3	8.7	0.0	26.1
	5.0 – 9.9mm	0.0	4.3	0.0	**17.4**	0.0	21.7
	>10.0mm	0.0	0.0	0.0	0.0	0.0	0
	TOTAL	21.7	39.1	8.7	30.4	0.0	**100.0**

Table 53: Characterisation of the enthesopathies at the Achilles tendon insertion in the English individuals with DISH (%; n=21)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	4.8	4.8	0.0	0.0	0.0	9.5
	1.0 – 1.9mm	4.8	19.0	**23.8**	0.0	0.0	47.6
	2.0 – 4.9mm	0.0	0.0	14.3	0.0	0.0	14.3
	5.0 – 9.9mm	0.0	0.0	9.5	19.0	0.0	28.6
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	9.5	23.8	47.6	19.0	0.0	**100.0**

The Catalan individuals with DISH show a similar pattern of enthesopathies as the one observed when the entire sample was taken into account, however these results must be read with caution due to the relatively small size (Tables 54 – 56). At the *M. triceps brachii* and the *M. quadriceps femoris* insertions, most of the individuals show no or very minimal entheseal changes (92.3% and 42.9%) while the enthesis at the Achilles tendon most commonly show entheseal changes ranging from 1 to 2mm (33.3%). In this subsample, the trend observed in the entire Catalan sample; that is, an increased interpersonal variability of the entheseal changes at the insertion of the *M. quadriceps femoris* and of the Achilles tendon, is also observed (Tables 52 and 53).

Table 54: Characterisation of the enthesopathies at the *M. triceps brachii* insertion in the Catalan individuals with DISH (%; n=13)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**92.3**	0.0	0.0	0.0	0.0	92.3
	1.0 – 1.9mm	7.7	0.0	0.0	0.0	0.0	7.7
	2.0 – 4.9mm	0.0	0.0	0.0	0.0	0.0	0.0
	5.0 – 9.9mm	0.0	0.0	0.0	0.0	0.0	0.0
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	100.0	0.0	0.0	0.0	0.0	**100.0**

Table 55: Characterisation of the enthesopathies at the *M. quadriceps femoris* insertion in the Catalan individuals with DISH (%; n=14)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	**42.9**	0.0	0.0	0.0	0.0	42.9
	1.0 – 1.9mm	7.1	14.3	7.1	0.0	0.0	28.6
	2.0 – 4.9mm	7.1	0.0	7.1	0.0	0.0	14.3
	5.0 – 9.9mm	0.0	0.0	14.3	0.0	0.0	14.3
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	57.1	14.3	28.6	0.0	0.0	**100.0**

Table 56: Characterisation of the enthesopathies at the Achilles tendon insertion in the Catalan individuals with DISH (%; n=15)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	TOTAL
Left side	Smooth-uneven	13.3	0.0	0.0	0.0	0.0	13.3
	1.0 – 1.9mm	0.0	**33.3**	6.7	0.0	0.0	40.0
	2.0 – 4.9mm	0.0	13.3	20.0	0.0	0.0	33.3
	5.0 – 9.9mm	0.0	0.0	6.7	6.7	0.0	13.3
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	13.3	46.7	33.3	6.7	0.0	**100.0**

The final three tables aim to draw attention to the individuals with DISH without taking into consideration their origin and explore whether, in general, they tend to have more developed entheseal changes. Tables 57 – 59 show that, in fact, individuals with DISH show the same trends observed in the general sample: symmetrical absence of enthesophytes at the insertion of the *M. triceps brachii* at the olecranon (Table 57) and at the insertion of the *M. quadriceps femoris* at the patella (Table 58) and slightly more developed enthesophytes at the insertion of the Achilles tendon in the calcaneal tuberosity (Table 59). Furthermore, as the highest percentage at the *M. quadriceps femoris* and the Achilles tendon is 27.0% and 25.0% respectively, the pattern previously identified suggesting that these sites showed greater interpersonal variability is also reproduced when only the individuals with DISH are taken into account. Finally, while the pattern observed in the individuals with DISH is comparable to that observed in the entire sample, it is notable that the percentages of the 'most common enthesopathies range' is actually lower in the individuals with DISH suggesting that, possibly, individuals with DISH show a greater variability in the development of the enthesopathies. This findings agree with the study of the individuals from the Bass Collection (Table 10 in section A.3.5.1; section A.4.6 for discussion).

Table 57: Characterisation of the enthesopathies at the insertion of the *M. triceps brachii* in the individuals with DISH in the combined English and Catalan samples (%; n=38)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**63.2**	2.6	0.0	5.3	0.0	71.1
	1.0 – 1.9mm	5.3	10.5	7.9	2.6	0.0	26.3
	2.0 – 4.9mm	0.0	0.0	0.0	0.0	0.0	0.0
	5.0 – 9.9mm	0.0	0.0	0.0	2.6	0.0	2.6
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	68.4	13.2	7.9	10.5	0.0	**100.0**

Table 58: Characterisation of the enthesopathies at the insertion of the *M. quadriceps femoris* in the individuals with DISH in the combined English and Catalan samples (%; n=37)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	**27.0**	5.4	0.0	0.0	0.0	32.4
	1.0 – 1.9mm	5.4	13.5	5.4	2.7	0.0	27.0
	2.0 – 4.9mm	2.7	8.1	5.4	5.4	0.0	21.6
	5.0 – 9.9mm	0.0	2.7	5.4	10.8	0.0	18.9
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0
	TOTAL	35.1	29.7	16.2	18.9	0.0	**100.0**

Table 59: Characterisation of the enthesopathies at the insertion of the Achilles tendon in the individuals with DISH in the combined English and Catalan samples (%; n=36)

		Right side					
		Smooth-uneven	1.0 – 1.9mm	2.0 – 4.9mm	5.0 – 9.9mm	>10.0mm	**TOTAL**
Left side	Smooth-uneven	8.3	2.8	0.0	0.0	0.0	11.1
	1.0 – 1.9mm	2.8	**25.0**	16.7	0.0	0.0	44.4
	2.0 – 4.9mm	0.0	5.6	16.7	0.0	0.0	22.2
	5.0 – 9.9mm	0.0	0.0	8.3	13.9	0.0	22.2
	>10.0 mm	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	11.1	33.3	41.7	13.9	0.0	**100.0**

Table 60 summarises the findings reported from table 42 to 59 regarding the state of the entheses in Catalan and English populations when the entire population or only the individuals with DISH are taken into account. The most common state of the *M. triceps brachii* enthesis at the olecranon and of the *M. quadriceps femoris*, at the base of the patella, is smooth or uneven for all the populations. In contrast, entheseal changes found at the insertion of the Achilles tendon tend show slightly bigger entheses although usually smaller than 2mm.

Table 60: Summary of the most common finding in the enthesopathy analysis of the Catalan and English populations

Region	Pop.	Enthesis	Most common	n.	%
Catalonia	All	*Triceps brachii m.*	Smooth-uneven	121	88.0
		Quadriceps femoris m.	Smooth-uneven	91	66.2
		Achilles tendon	Spicules-1.9mm	120	31.4
	DISH	*Triceps brachii m.*	Smooth-uneven	13	92.3
		Quadriceps femoris m.	Smooth-uneven	14	42.9
		Achilles tendon	Spicules-1.9mm	15	33.3
English	All	*Triceps brachii m.*	Smooth-uneven	199	70.7
		Quadriceps femoris m.	Smooth-uneven	162	49.3
		Achilles tendon	Spicules-1.9mm	152	32.8
	DISH	*Triceps brachii m.*	Smooth-uneven	25	48.8
		Quadriceps femoris m.	Smooth-uneven	23	17.4
		Achilles tendon	Spicules-1.9mm	21	23.8*
Combined	All	*Triceps brachii m.*	Smooth-uneven	320	77.3
		Quadriceps femoris m.	Smooth-uneven	253	55.3
		Achilles tendon	Spicules-1.9mm	272	32.2
	DISH	*Triceps brachii m.*	Smooth-uneven	38	63.2
		Quadriceps femoris m.	Smooth-uneven	37	27.0
		Achilles tendon	Spicules-1.9mm	36	25.0

It is notable that for all the entheseal sites analysed, the enthesopathy appeared symmetrical within the selected range. This is not surprising as only in the specific cases of unilateral appendicular pathology or activity, asymmetric entheseal changes should be expected. However the combination of the results obtained from the analysis of enthesopathies in individuals with and without DISH suggest that DISH-related enthesopathies cannot be differentiated from the age or activity-related based only on their symmetric character. Furthemore, in accordance with the results obtained from the individuals from the Bass Collection, it seems that the presence of extra-spinal enthesopathies varies between individuals independently of their DISH status.

B.5.8.3 Relationship between sex, age and enthesophyte development in individuals from the combined Catalan and the English samples

As the English and Catalan samples showed statistically similar demographic profiles (B.5.1) and, the pattern of entheseal changes is also similar, the two samples have been combined investigate the relationship between sex, age and size of the extra-spinal manifestations. It was hypothesised that male and older individuals would show bigger enthesophytes. Figures 91 – 93 show how the different categories of entheseal changes are represented within each age cohort. To make these plots, the size of the left enthesophyte has been used. In the case the left olecranon, patella or calcaneus was too damaged or absent, the right side has been used instead since, as it has previously been shown, in the majority of cases, left and right enthesophytes are of similar sizes. Finally, only individuals whose sex could be assessed and age estimated (maximum likelihood of age at death) were included in the plots.

The majority of the individuals (73.8%) whose olecranon could be analysed show no changes at the insertion of the *M. triceps brachii.* There seems to be no differences between males and females as 7.1% of females and 7.7% of males show enthesophytes bigger than a milimetre (Figures 91).

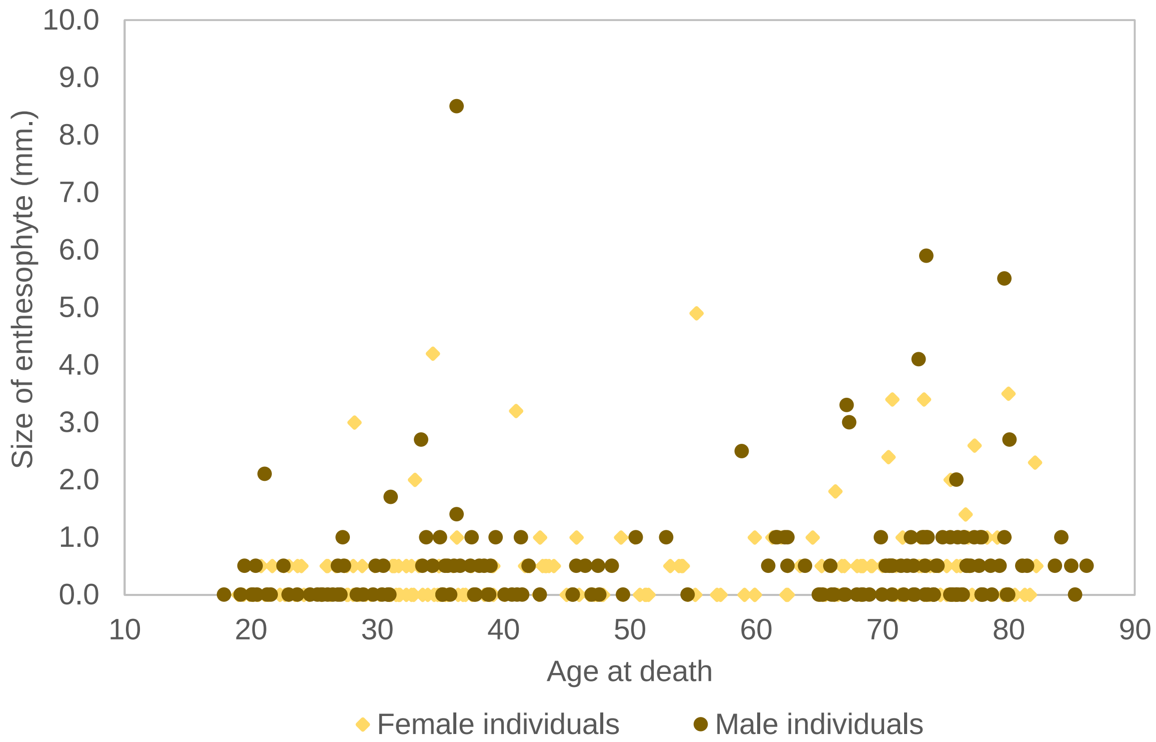


Figure 91: Relationship between age and size of enthesophyte at the *M. triceps brachii* insertion in the combined sample (Female=197; Male=196)

Similarly, Figure 92 shows that the majority of individuals (78.8%), males and females, show no or very small enthesophytes at the insertion of the *M. quadriceps femoris* (Figure 92). In this case, 17.7% of females and 24.7% of males show enthesophytes bigger than a milimetre, a difference that could suggest a bias in the development of enthesophytes at this site. Nevertheless, there does not seem to be a clear relationship between age and size of the biggest enthesophyte, in fact the distribution of data is almost bimodal – which could be related to the bimodal distribution of the Catalan and English populations (Figures 72 and 73 in section B.5.1.5).

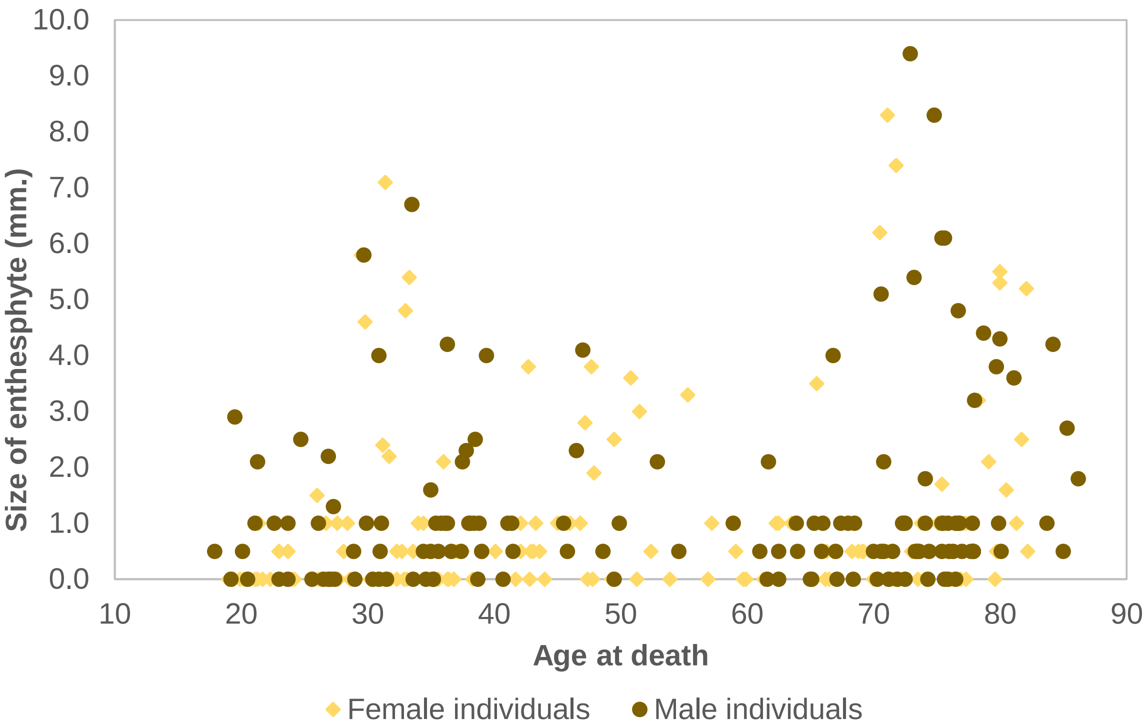


Figure 92: Relationship between age and size of enthesophyte at at the *M.quadriceps femoris* insertion in the combined sample (Female=164; Male=146)

Finally, the majority of individuals (66.9%) also show enthesophytes of less than a milimetre at the insertion of the Achilles tendon at the calcaneal tuberosity. In this case, 27.3% of females and 39.4% of males show enthesophytes bigger than a milimetre, which could also suggest an underlying bias in the development of entheseal changes at this site. Compared to the insertions at the olecranon and at the base of the patella, there are significantly less individuals showing no enthesophytes at the calcaneal tuberosity. Finally, while the trend is far for clear, Figure 93, seems to show that some old individuals show bigger enthesophytes which could suggest that this is the only location where age and enthesophyte size might be related.

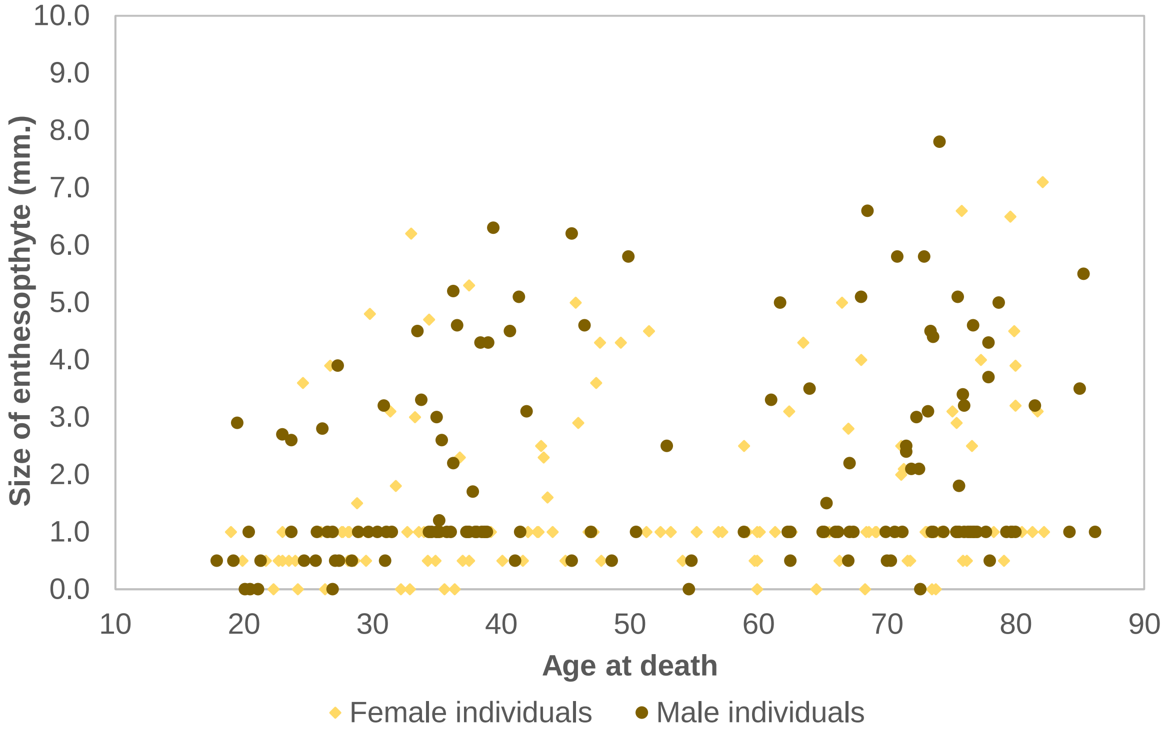


Figure 93: Relationship between age and size of enthesophyte at at the Achilles tendon insertion in the combined sample (Female=150; Male=137)

B.5.8.4 Relationship between entheseal changes and stages of DISH development

To try to understand the greater variation found in the expression of the extra-spinal enthesopathies in individuals with DISH. Following the rational exposed in Part A, it was hypothesised that the severity of the spinal changes would correspond with a bigger size in the extra-spinal enthesopathies. Figure 94 depicts the relationship between the size of the extra-spinal enthesopathies and the stage of DISH. To make Figure 94, the values obtained from the Catalan and the English samples have been combined.

In most cases, the *M. triceps brachii* insertion show no entheseal changes and thus no correlation with the stages of development of the spinal ankylosis. As previously highlighted, the insertions of the *M. quadriceps femoris* at the patella and the Achilles tendon at the calcaneal tuberosity show a higher interpersonal variation however, this variability does not seem to be related in any way to the stages of development of the spinal ankylosis. These results support the findings from the Bass Collection suggesting no correlation between the size of the extra-spinal manifestations and the number of vertebrae involved in the spinal ankylosis (Table 10, section A.3.5.2). These results reinforce the idea that while some individuals with spinal ankylosis do show extra-spinal enthesopathy, the relationship between these two features is not straight forward and the presence of one might not determine the presence of the other (see section A.4.6 for discussion).

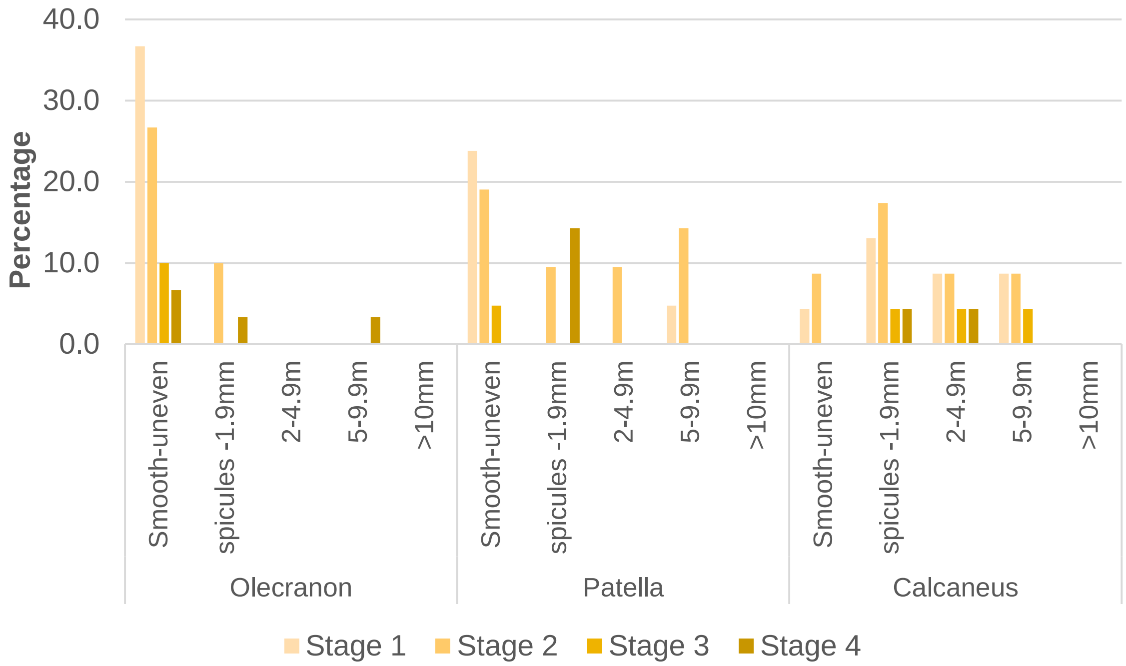


Figure 94: Correlation between stage of DISH development and size of the enthesopathies in the combined English and Catalan sample (%; n=30, 21 and 23 respectively)

B.5.9 Study of the co-morbidities between DISH and other nutrition and metabolism-related conditions

In this last section, the results regarding the relationship between several nutrition and metabolism-related condition and the DISH status are explored. First, the two regions are analysed separately to investigate the possible existence of regional patterns and second, both samples have been combined with the aim of exploring the possible co-morbidities. The overall prevalence of each disease has been calculated using the "total observable" value. See Appendices from 4.11 to 4.18 for the detailed report of the pathologies observed in each individual.

When calculating the prevalence of gout, in the case where there were no first metatarsals, the individual was considered was “Not obs./Not obs.” if there was one of metatarsal recovered with no signs of gout and when both sides were observable but showed no signs of gout, the individual was classified as “No gout”. If only one element was recovered and it showed gouty lesions, the individual was classified as “possible unilateral” or “unilateral” depending on certainty of the diagnostic. If right and left first metatarsals had been recovered, the individual was also classified as “possibly unilateral/bilateral” or “unilateral/bilateral” depending on the certainty of the diagnosis and the location of the lesion. Finally, if an individual showed one definitive and one possible lesion, it was classified as “possibly bilateral”. Therefore all the cases of gout were included and recorded as they were observed without assuming the presence of symmetrical lesions in the cases were only one side was recovered.

Only the weight bearing joints were considered in the analysis of osteoarthritis and if an individual showed poly-articular OA, each join was recorded individually. If an individual showed poly-articular OA, it was included once in “overall OA”. Finally, with regards to the recording of carious lesions, if no teeth were recovered, the individual was classified as “not observable”. If teeth had been recovered, the number of carious lesions was recorded as observed.

Table 61: DISH and nutrition excess-related co-morbidities in English sample

a. Gout

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not obs. / Not obs.	73	29.9	10	27.8
Total observable	**171**		**26**	
No gout	162	94.7	24	92.3
Possible unilateral	2	1.2	0	0.0
Possible bilateral	2	1.2	0	0.0
Unilateral	3	1.8	1	3.8
Bilateral	2	1.2	1	3.8
Overall gout	**9**	5.3	**2**	7.7

b. Osteoarthritis

Status	No DISH	%	DISH	%
Total analysed	**245**		**37**	
Not observable	9	3.7	2	5.4
Total observable	**236**		**35**	
No OA	214	90.7	29	82.9
Hip bilateral	1	0.4	0	0.0
Hip unilateral	6	2.5	3	8.6
Knee bilateral	2	0.8	0	0.0
Knee unilateral	5	2.1	2	5.7
Foot Bilateral	0	0.0	0	0.0
Foot unilateral	8	3.4	1	2.9
Overall OA	**22**	**9.3**	**5**	**14.3**

c. Carious lesions

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not observable	45	18.4	7	19.4
Total observable	**199**		**29**	
No lesions	100	50.3	15	51.7
1 lesion	43	21.6	8	27.6
2 lesions	31	15.6	1	3.4
3 lesions	15	7.5	2	6.9
3+ lesions	10	5.0	3	10.3
Overall CL	**99**	**49.7**	**14**	**48.3**

Figures 95 and 96 show the prevalence of gout, osteoarthritis and carious lesions in the English and Catalan samples (data in Tables 61 and 62 respectively). To make this graph, the calculations were made using the “total of observable” values.

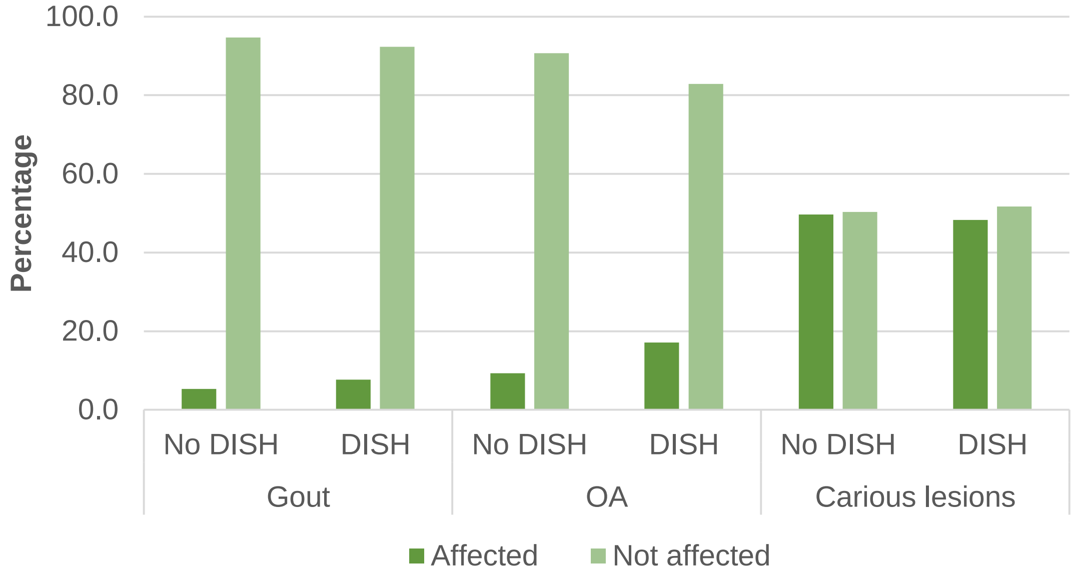


Figure 95: Prevalence of gout, osteoarthritis and carious lesions in English individuals with and without DISH (%)

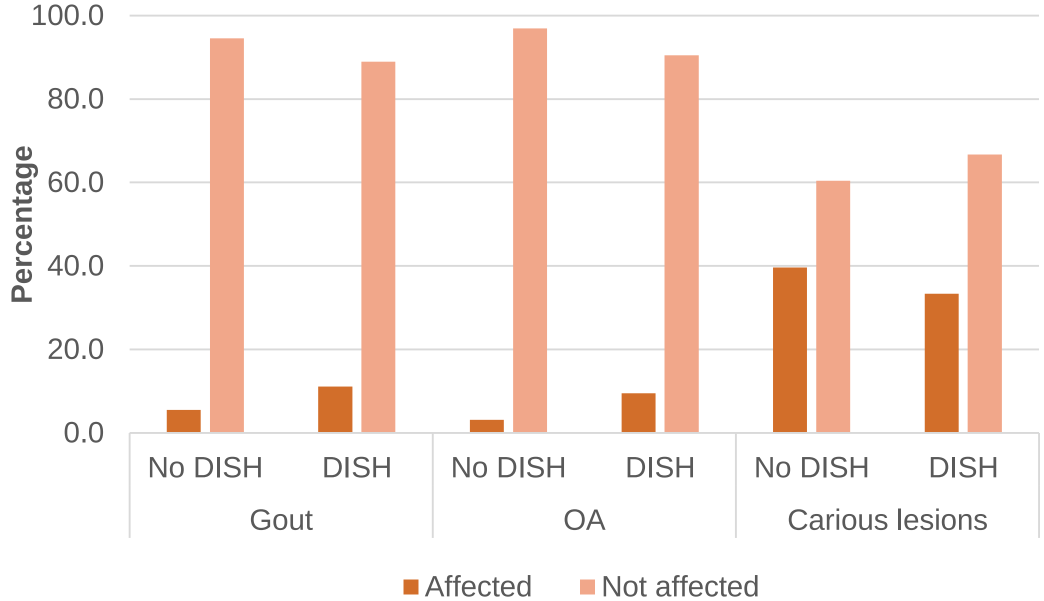


Figure 96: Prevalence of gout, osteoarthritis and carious lesions in Catalan individuals with and without DISH (%)

The overall prevalence of gout in the Catalan and the English sample is similar (11.0% and 7.7% respectively) and in none of them there seems to be difference in the prevalence of this condition in individuals with DISH and without DISH (Tables 61a and 62a). Comparatively, there is a statistically significant difference in the prevalence of OA in the English and the Catalan sample (10.0% and 3.8% respectively; Chi-Square p=0.005). In both samples there seems to be a slightly higher prevalence of OA in individuals with DISH (Tables 61b and 62b) however a Fisher’s Exact test evaluating the dependency between status of DISH and presence of OA (considered as presence versus absence) suggest that these two conditions are not related (England: p=371; Catalonia: p=0.176).

Table 62: DISH and nutritional excess-related co-morbidities in Catalan sample

a. Gout

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not obs. / Not obs.	98	43.6	4	18.2
Total observable	**127**		**18**	
No gout	120	94.5	16	88.9
Possible unilateral	3	2.4	0	0.0
Possible bilateral	0	0.0	1	5.6
Unilateral	3	2.4	0	0.0
Bilateral	1	0.8	1	5.6
Overall gout	**7**	5.5	**2**	**11.1**

b. Osteoarthritis

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not observable	30	13.3	1	4.5
Total observable	**195**		**21**	
No OA	189	96.9	19	86.4
Hip bilateral	0	0.0	0	0.0
Hip unilateral	0	0.0	0	0.0
Knee bilateral	3	1.5	0	0.0
Knee unilateral	2	1.0	1	4.5
Foot Bilateral	0	0.0	0	0.0
Foot unilateral	1	0.5	1	4.5
Overall OA	**6**	**3.1**	**2**	**9.5**

c. Carious lesions

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not observable	71	31.5	7	31.8
Total observable	**154**		**15**	
No lesions	93	60.4	10	66.7
1 lesion	37	24.0	3	20.0
2 lesions	13	8.4	1	6.7
3 lesions	7	4.5	1	6.7
3+ lesions	4	2.6	0	0.0
Overall CL	**61**	**39.6**	**5**	**33.3**

The pattern for the last of the ”excess-related” conditions, carious lesions, is very similar to that of osteoarthrosis. The English sample show a higher prevalence compared to the Catalan sample (49.5% and 39.0% respectively). In both, English and Catalan samples, the prevalence of carious lesions is similar in both subsamples (individuals with and without DISH) suggesting an absence of correlation between these two conditions (Table 61c and 62c).

With regards to the conditions described as deficiency-related (scurvy, healed rickets, osteomalacia and linear enamel hypoplasia), the English sample seem to have slightly higher prevalence of scurvy (Eng.: 9.3%; Cat.: 2.3%). As expected, in both the English and the Catalan samples, the individuals with DISH show consistently lower prevalence of scurvy compared to the subsamples of individuals without DISH. The prevalence of DISH in Catalan and English populations without DISH is very similar (Eng.: 10.2%; Cat.: 10.9%). Interestingly, the English and the Catalan individuals with and without DISH show very similar prevalence of healed rickets. Therefore the analysis of their co-morbidity with DISH seems to suggest that not scurvy neither rickets nor osteomalacia are associated with DISH (Tables 63 and 64 and Figures 97 and 98). There was an unexpected case of possible osteoporosis combined with stage 4 DISH in the late medieval site of York Fishergate House (Ind. 1579), while further analysis is needed to confirm this diagnosis it was suspected due to the presence of multiple rib fractures at different stages of healing and the considerable reduction of cortical bone thickness and trabecular density in all long bones, pelvis and vertebral bodies.

Table 63: DISH and nutrition deficiency-related co-morbidities in English sample

a. Scurvy

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not observable	48	16.7	5	13.9
Total observable	**196**		**31**	
No scurvy	176	89.8	30	93.8
Possible	6	3.1	0	0.0
Probable	8	4.1	1	3.1
Definite	6	3.1	0	0.0
Overall scurvy	**20**	**10.2**	**1**	**3.2**

b. Healed rickets

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not observable	28	11.5	4	11.1
Total observable	**216**		**32**	
No rickets	194	89.8	28	87.5
Possible	14	6.5	1	3.1
Probable	3	1.4	2	6.2
Definite	5	2.3	1	3.1
Overall h. rickets	**22**	**10.2**	**4**	**12.5**

c. Osteomalacia

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not observable	3	1.2	2	5.6
Total observable	**241**		**34**	
No osteomalacia	241	100	34	100
Possible	0	0.0	0	0.0
Probable	0	0.0	0	0.0
Definite	0	0.0	0	0.0
Overall osteomalacia	**0**	**0.0**	**0**	**0.0**

d. Linear enamel hypoplasia

Status	No DISH	%	DISH	%
Total analysed	**244**		**36**	
Not observable	52	21.3	11	30.6
Total observable	**192**		**25**	
No LEH	124	64.6	12	48.0
1 line	30	15.6	7	28.0
2 lines	18	9.4	0	0.0
3 lines	10	5.2	3	12.0
3+ lines	10	5.2	3	12.0
Overall LEH	**68**	**35.4**	**13**	**52.0**

Regarding linear enamel hypoplasia, the overall percentage of individuals with at least one event of linear enamel hypoplasia in the English and the Catalan sample very is similar (37.3% and 35.8% respectively). However, while in the Catalan sample and the 'English individuals without DISH' subsample there is a higher percentable of individuals without LEH, in the 'English individuals with DISH' subsample, the percentage of individuals with LEH is slightly higher than the percentage of individuals with DISH but without DISH (Table 63d, Figure 97). The difference in the percentage of individuals with and without DISH and showing LEH is not statistically significant (X^2=2.600; p=0.107). Nevertheless, could there be an association between surviving the childhood stress period which would have triggered the development of LEH and the posterior development of DISH? If that is the case, why this association is only observed in the English but not in the Catalan sample (Figure 97 *versus* 98)? These questions cannot be answered as only adult individuals were analysed in this project.

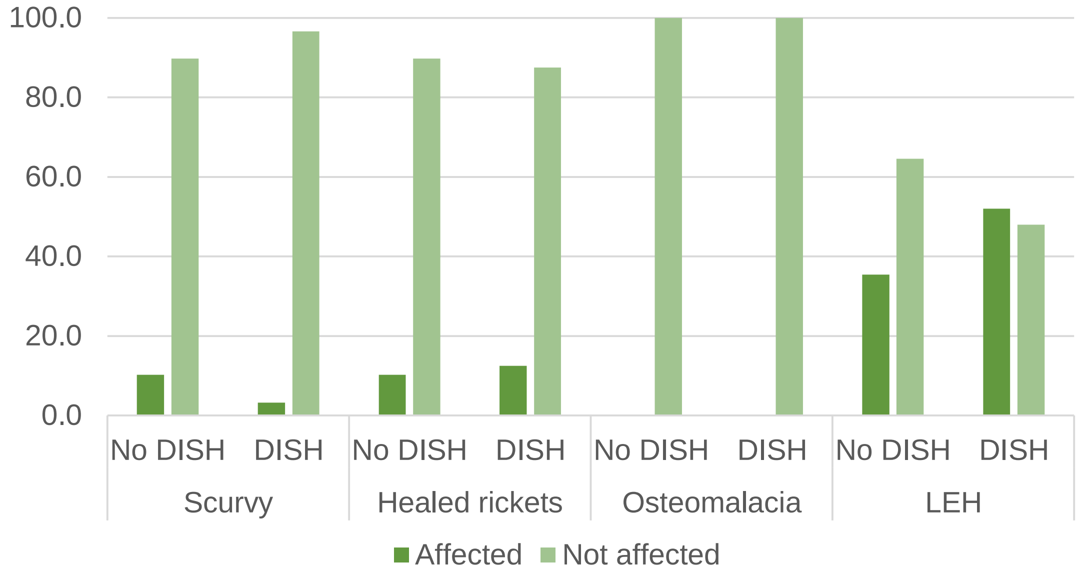


Figure 97: Prevalence or scurvy, healed rickets, osteomalacia and linear enamel hypoplasia in English individuals with and without DISH (%)

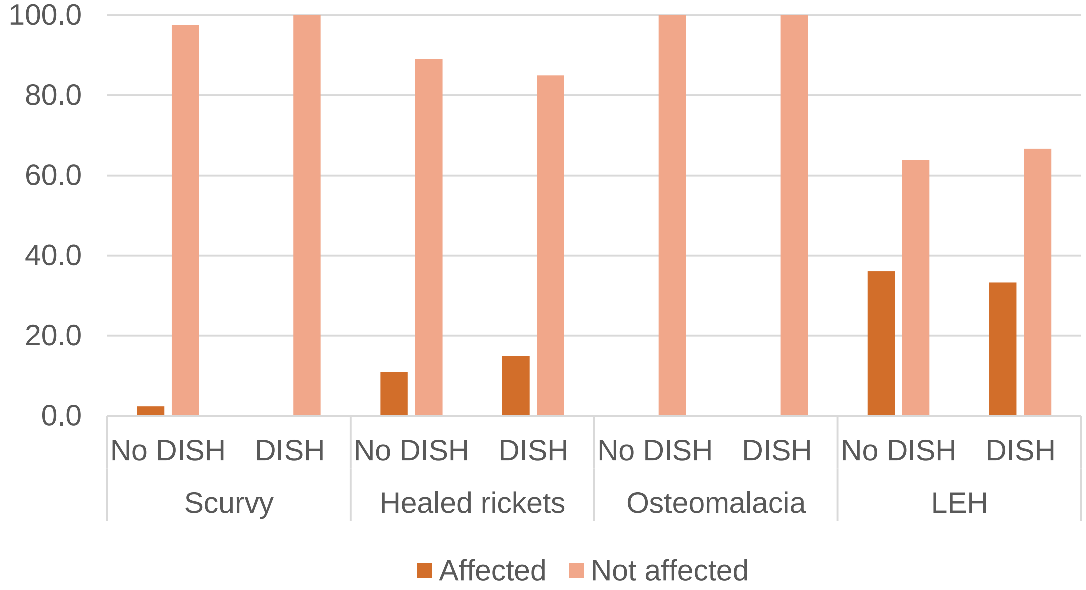


Figure 98: Prevalence or scurvy, healed rickets, osteomalacia and linear enamel hypoplasia in Catalan individuals with and without DISH

Table 64: DISH and nutrition deficiency-related co-morbidities in Catalan sample

a. Scurvy

Status	No DISH	%	DISH	%
Total analysed	**225**		**16**	
Not observable	102	45.3	9	56.3
Total observable	**123**		**7**	
No scurvy	120	97.6	7	100.0
Possible	2	1.6	0	0
Probable	1	0.8	0	0
Definite	0	0.0	0	0
Overall scurvy	**3**	**2.4**	**0**	**0**

b. Healed rickets

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not observable	51	22.7	2	9.1
Total observable	**174**		**20**	
No rickets	155	83.3	17	80.0
Possible	11	6.9	1	5.0
Probable	4	5.2	0	0.0
Definite	4	4.6	2	15.0
Overall h. rickets	**19**	**10.9**	**3**	**15.0**

c. Osteomalacia

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not observable	24	10.7	0	0
Total observable	**201**		**22**	
No osteomalacia	201	100	22	100
Possible	0	0	0	0
Probable	0	0	0	0
Definite	0	0	0	0
Overall osteomalacia	**0**	**0.0**	**0**	**0.0**

d. Linear enamel hypoplasia

Status	No DISH	%	DISH	%
Total analysed	**225**		**22**	
Not observable	81	36.0	7	31.8
Total observable	**144**		**15**	
No LEH	92	63.9	10	66.7
1 line	17	11.8	2	13.3
2 lines	14	9.7	1	6.7
3 lines	14	9.7	0	0.0
3+ lines	7	4.9	2	13.3
Overall LEH	**52**	**36.1**	**5**	**33.3**

The results obtained from the combined samples aimed to understand the co-morbidities between DISH and gout, osteoarthritis and carious lesions do not differ from those obtained when the samples were considered separately (Figure 99, table 65). Gout is as prevalent in individuals with and without DISH and OA is slightly more prevalent in the individuals with DISH; however the majority of the individuals with DISH showed no arthritic changes in their weight bearing joints and table 66 shows that the prevalence of gout is the same in young and old adult individuals. No significant association was observed between age and osteoarthritis (Chi square: p=0.287, respectively) either despite the fact the prevalence of these conditions is higher in old individuals compared to the young individuals (Table 66).

Table 65: DISH and nutrition excess-related co-morbidities in the combined English and Catalan sample

a. Gout

Status	No DISH	%	DISH	%
Total analysed	**469**		**58**	
Not obs. / Not obs.	171	35.4	14	24.1
Total observable	**298**		**44**	
No gout	**282**	94.6	**40**	90.9
Possible unilateral	**5**	1.7	**0**	0.0
Possible bilateral	**2**	0.7	**1**	2.3
Unilateral	**6**	2.0	**1**	2.3
Bilateral	**3**	1.0	**2**	4.5
Overall gout	**16**	5.4	**4**	9.1

b. Osteoarthritis

Status	No DISH	%	DISH	%
Total analysed	**470**		**59**	
Not observable	39	8.3	3	5.1
Total observable	**431**		**56**	
No OA	403	93.5	48	85.7
Hip bilateral	1	0.2	0	0.0
Hip unilateral	6	1.4	3	5.4
Knee bilateral	5	1.2	0	0.0
Knee unilateral	7	1.6	3	5.4
Foot Bilateral	0	0.0	0	0.0
Foot unilateral	9	2.1	2	3.6
Overall OA	**28**	**6.5**	**7**	**12.5**

c. Carious lesions

Status	No DISH	%	DISH	%
Total analysed	**469**		**58**	
Not observable	116	24.7	14	24.1
Total observable	**353**		**44**	
No lesions	193	54.7	25	56.8
1 lesion	80	22.7	11	25.0
2 lesions	44	12.5	2	4.5
3 lesions	22	6.2	3	6.8
3+ lesions	14	4.0	3	6.8
Overall CL	**160**	**45.3**	**19**	**43.2**

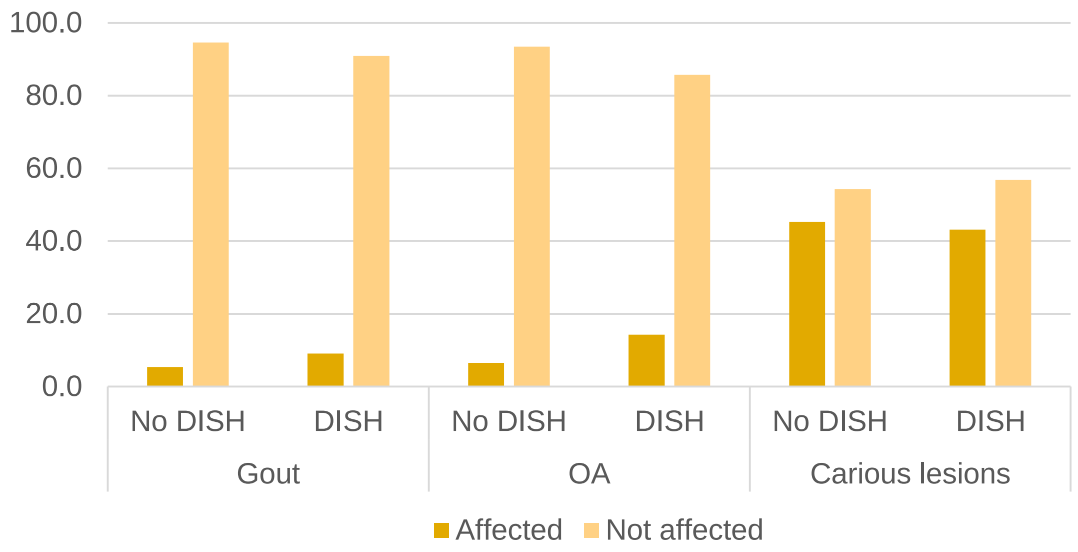


Figure 99: Prevalence of gout, osteoarthritis and carious lesions in individuals with and without DISH in the combined English and Catalan sample (%)

There was no relationship either between the presence of at least one carious lesion and DISH however in this case, the percentage of individuals with DISH with carious lesions was very similar to the percentage of individuals without DISH but with carious lesions.

Table 66: Relationship between age and gout and osteoarthritis in the combined English and Catalan sample

	Gout			OA		
	N.	**No gout**	**Gout**	**N.**	**No OA**	**OA**
Young adult	114	105 (92.1)	9 (7.9)	160	151 (94.4)	9 (5.6)
Middle adult	50	50 (100.0)	0 (0.0)	70	62 (88.6)	8 (11.6)
Old adult	129	119 (92.2)	10 (7.8)	182	166 (91.2)	16 (8.8)

Also similarly to the results obtained when the English and Catalan samples were considered separately, when combined, there seems to be very few cases of co-morbidity between DISH and deficiency-related conditions (Table 67, Figure

100). There is no significant difference between the percentage of individuals with DISH and scurvy or rickets and that of individuals with only scurvy or residual rickets. In fact, the majority of the sample, despite their DISH status, do not show signs of having suffered these conditions. Finally, the presence of linear enamel hypoplasia is widespread in both groups (individuals with and without DISH).

Table 67: DISH and nutrition deficiency-related co-morbidities in the combined English and Catalan sample

a. Scurvy

Status	No DISH	%	DISH	%
Total analysed	**469**		**52**	
Not observable	150	32.0	14	26.9
Total observable	**319**		**38**	
No scurvy	296	92.8	37	97.4
Possible	8	2.5	0	0.0
Probable	9	2.8	1	2.6
Definite	6	1.9	0	0.0
Overall scurvy	**23**	**7.3**	**1**	**2.6**

b. Healed rickets

Status	No DISH	%	DISH	%
Total analysed	**469**		**58**	
Not observable	79	16.8	6	10.3
Total observable	**390**		**52**	
No rickets	349	89.5	45	86.5
Possible	25	6.4	2	3.8
Probable	7	1.8	2	3.8
Definite	9	2.3	3	5.8
Overall h. rickets	**41**	**10.5**	**8**	**13.5**

c. Osteomalacia

Status	No DISH	%	DISH	%
Total analysed	**468**		**58**	
Not observable	27	5.8	2	3.5
Total observable	**441**		**56**	
No osteomalacia	441	100.0	56	100
Possible	0	0.0	0	0.0
Probable	0	0.0	0	0.0
Definite	0	0.0	0	0.0
Overall osteomalacia	**0**	**0.0**	**0**	**0.0**

d. Linear enamel hypoplasia

Status	No DISH	%	DISH	%
Total analysed	**469**		**58**	
Not observable	133	28.4	18	31.0
Total observable	**336**		**40**	
No LEH	216	64.3	22	55.0
1 line	47	14.0	9	22.5
2 lines	32	9.5	1	2.5
3 lines	24	7.1	3	7.5
3+ lines	17	5.1	5	12.5
Overall LEH	**120**	**35.7**	**18**	**45.0**

As the majority of the sample, with or without DISH, did not suffer any co-morbidity and when nutrition-related or metabolic conditions were present, the prevalence in both samples was so similar, it was not considered to apply further statistical tests since these would have not added extra valuable information but would have increased the probability of producing type 2 or false negative errors.

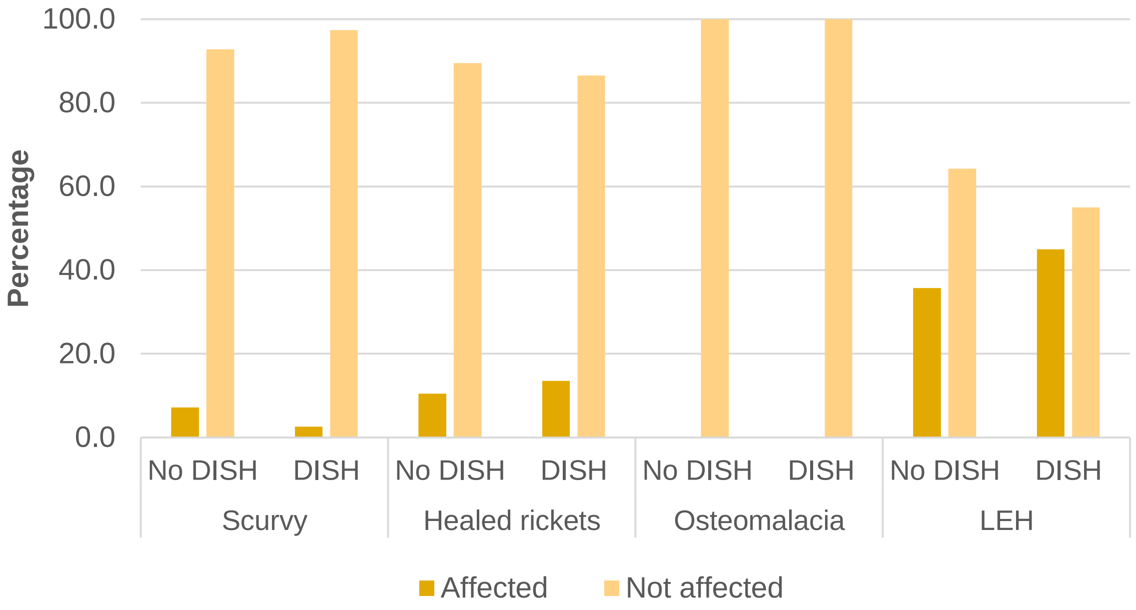


Figure 100: Prevalence or scurvy, healed rickets, osteomalacia and linear enamel hypoplasia in individuals with and without DISH in the combined sample (%)

To summarise the findings from this last section, the individuals with DISH do not seem to have had a higher or lower probability of having suffered from other excess or deficiency-related conditions. While this might be surprising given all the clinical data suggesting that DISH is related to other metabolic conditions, it is possible that the type of sample might have influenced these results. Furthermore, several of these so-called metabolic imbalances (e.g. hypercholesterolemia, hypertension or diabetes) are still invisible to the palaeopathologist and the diagnosis of obesity is still very controversial.

B.5.10 Summary of the results

The data obtained from the individuals with DISH from the analysis of archaeological human remains dated between the Roman and the post-medieval periods from England and Catalonia can be summarised in the following points:

- The samples from the Roman period show the lowest prevalence of DISH. Early medieval samples show the highest prevalence of all while late medieval samples show prevalence rates that are intermediate between the Roman and the early medieval samples. The observed differences are not statistically significant (See sections B.7.2-5 for discussion).
- All English populations show higher prevalence of DISH compared to the contemporaneous Catalan samples (See sections B.7.2-5 for discussion).
- The prevalence of advanced DISH remains significantly constant through time. The temporal fluctuations of prevalence observed in the Catalan and English samples are at the expense of the changing prevalence of early DISH (stages 1 and 2) (See sections B.7.2-5 for discussion).
- In all samples for both regions, the prevalence of DISH is higher in males than in females (See sections B.7.9 for discussion).
- In all samples for both regions, old individuals show higher prevalence of advanced DISH but this relationship is not statistically significant. Young and middle adult individuals tend to show early stages of DISH while old individuals can show lesions at any stage of development (See sections B.7.9 for discussion).

- Not including young adult individuals and not considering the early stages of development of DISH can significantly underestimate the prevalence of DISH and of developing DISH.
- Archaeological human remains with DISH seem to show a higher variation in the distribution of the ankylosis than the modern individuals from the Bass collection (See sections B.7.10 for discussion).
- Discarthrosis can be observed in individuals with DISH from archaeological contexts. English samples seem to show higher prevalence of discarthrosis than Catalan samples (See sections B.7.11 for discussion).
- Individuals with and without DISH seem to show similar bilateral enthesopathic changes at the insertion of the *M. triceps brachii, M quadriceps femoris* and Achilles tendon. The enthesophytes at the insertion of the *M quadriceps femoris* and of the Achilles tendon show the highest inter-individual variation. The size of the enthesophytes at the insertion of the Achilles tendon seems to increase with age. There is a higher percentage of males with enthesophytes bigger than a milimetre at the insertion of the *M. quadriceps femoris* and Achilles tendon than females (See sections B.7.11 for discussion).
- There is no clear relationship between the size of the entheseal changes at the *M. triceps brachii, M quadriceps femoris* and Achilles tendon insertions and the stage of development of DISH (See sections B.7.11 for discussion).
- The prevalence of nutrition and metabolic-related co-morbidities in individuals with and without DISH is very similar for both excess and

deficiency-associated conditions (gout, carious lesions and osteoarthritis and scurvy, healed rickets and linear enamel hypoplasia) (See sections B.7.12 for discussion).

- The English sample show a statistically significant higher prevalence of OA compared to the Catalan sample (See sections B.7.12 for discussion).
- No statistically significant association was found between age and OA and age and gout. However old individuals show higher prevalence rates of OA and gout than young individuals (See sections B.7.12 for discussion).

The macroscopic analysis presented in the previous chapter indicate that, English and Catalan samples show different prevalence of DISH across periods so isotope analysis to further investigate and characterise the dietary differences between the specific populations analysed was carried out. The Romano-British population and the Roman Catalan population were selected for this more in-depth analysis because they show a significantly different prevalence of DISH and its demography is also clearly distinct (i.e. DISH in very early stages of development affecting only older individuals) and DISH is believed to be related to diet. Furthermore, as a result of different traditions and influences, it is possible that their diet might have also been isotopically (see sections A.4.1.1 and A.4.2.1).

B.5.11 Results of the stable isotope analysis of the human and animal remains from the Romano sites of Baldock and Santa Caterina

Herein are presented the results from the stable C and N isotope analysis carried on human and animal remains from the Roman Catalan site of Santa Caterina, Catalonia and the Romano-British site of Baldock. The C/N ratios in all human and animal samples are 3.2 or 3.3 suggesting that collagen preservation was optimal and the values could be confidently used (van Klinken 1999).

B.5.11.1 Stable isotope results from Catalan and the Romano-British samples

B.5.11.1.1 Romano-British stable isotope results

Six faunal remains found inside the graves in the cemetery of Baldock were selected to create a baseline. In this case, there was three cattle and three sheep remains (Table 68). The carbon and nitrogen isotope result obtained from Baldock's cattle remains are comparable to published contemporary Romano-British cattle. In contrast, while the carbon values for the sheep/goat remains are similar to the published data, the nitrogen values are higher as the average ratio for the Baldock remains is 7‰ while the average for the other Romano-British sites is 6.1‰ possibly suggesting a regional difference (Appendix 5.1).

Table 68: Isotope data for the animal samples from Roman Baldock

ID	Species	$\delta^{15}N$‰	$\delta^{13}C$‰	Amt%N	Amt%C	C/N
BAL 2232	Cattle 1	8.0	-22.2	18.2	50.1	3.2
BAL 1480	Cattle 2	4.7	-21.4	12.0	33.6	3.3
BAL 1480	Cattle 3	5.5	-21.4	16.0	44.1	3.2
BAL 1480	Sheep 1	7.9	-21.8	16.1	45.0	3.3
BAL 1480	Sheep 2	8.3	-21.7	17.3	47.7	3.2
BAL 1480	Sheep 3	7.8	-22.2	16.7	47.4	3.3
Average		**7.0**	**-21.8**			

The nitrogen isotope values obtained from the 33 individuals from Baldock range between 8.0‰ and 11.0‰, with an average of 9.8%, and the carbon isotope values range from -21.1‰ and -19.0‰ with an average of -20.2‰ (Table 69 and Figure 101). These results suggest that this Romano-British sample generally followed a terrestrial diet and the small ranges of variation suggest that most individuals either followed a similar diet or a different but isotopically equivalent diet.

Table 69: Isotope data for the human samples from Roman Baldock

Individual	δ^{15}N‰	δ^{13}C‰	Amt%N	Amt%C	C/N
BAL 1022	9.2	-20.7	17.3	48.1	3.2
BAL 1028	9.2	-19.9	28.7	77.8	3.2
BAL 1040	9.2	-19.9	17.5	48.1	3.2
BAL 1049	9.7	-19.3	17.5	48.3	3.2
BAL 1072	9.9	-20.0	17.7	48.5	3.2
BAL 1090	9.6	-20.0	16.5	45.8	3.2
BAL 1107	10.2	-19.9	18.1	49.7	3.2
BAL 1122	10.1	-20.1	17.1	47.5	3.2
BAL 1174	8.5	-19.9	17.8	49.0	3.2
BAL 1203	10.3	-20.5	18.0	49.6	3.2
BAL 1237	11.2	-20.9	17.7	49.1	3.2
BAL 1263	10.2	-21.1	17.2	48.1	3.3
BAL 1319	9.8	-20.1	16.8	46.0	3.2
BAL 1320	9.7	-20.4	15.1	42.3	3.3
BAL 1342	10.6	-20.6	18.3	50.2	3.2
BAL 1372	9.9	-20.7	18.3	49.3	3.1
BAL 1374	9.4	-20.0	17.5	48.3	3.2
BAL 1391	8.9	-20.3	17.9	49.0	3.2
BAL 1446	9.9	-20.7	17.8	48.4	3.2
BAL 1447	8.8	-20.4	17.2	46.8	3.2
BAL 2602	10.1	-21.0	19.2	52.1	3.2
BAL 3644	10.5	-20.1	16.5	45.7	3.2
BAL 833	10.0	-20.5	17.3	47.4	3.2
BAL F610-L1	10.0	-20.1	17.4	47.9	3.2
BAL F18-L10	9.2	-19.9	16.5	45.7	3.2
BAL F466	9.2	-19.5	15.5	43.3	3.3
BAL F475-L2	11.0	-19.2	16.5	45.9	3.3
BAL F644	9.9	-20.9	17.7	49.2	3.2
BAL 1077	9.7	-19.0	16.4	45.7	3.3
BAL 1281	8.0	-20.2	13.3	36.7	3.2
BAL 1480	10.2	-19.8	16.2	44.8	3.2
BAL 2225	9.7	-20.2	18.2	50.2	3.2
BAL F92	10.1	-20.1	16.3	45.0	3.2
Average	**9.8**	**-20.2**			

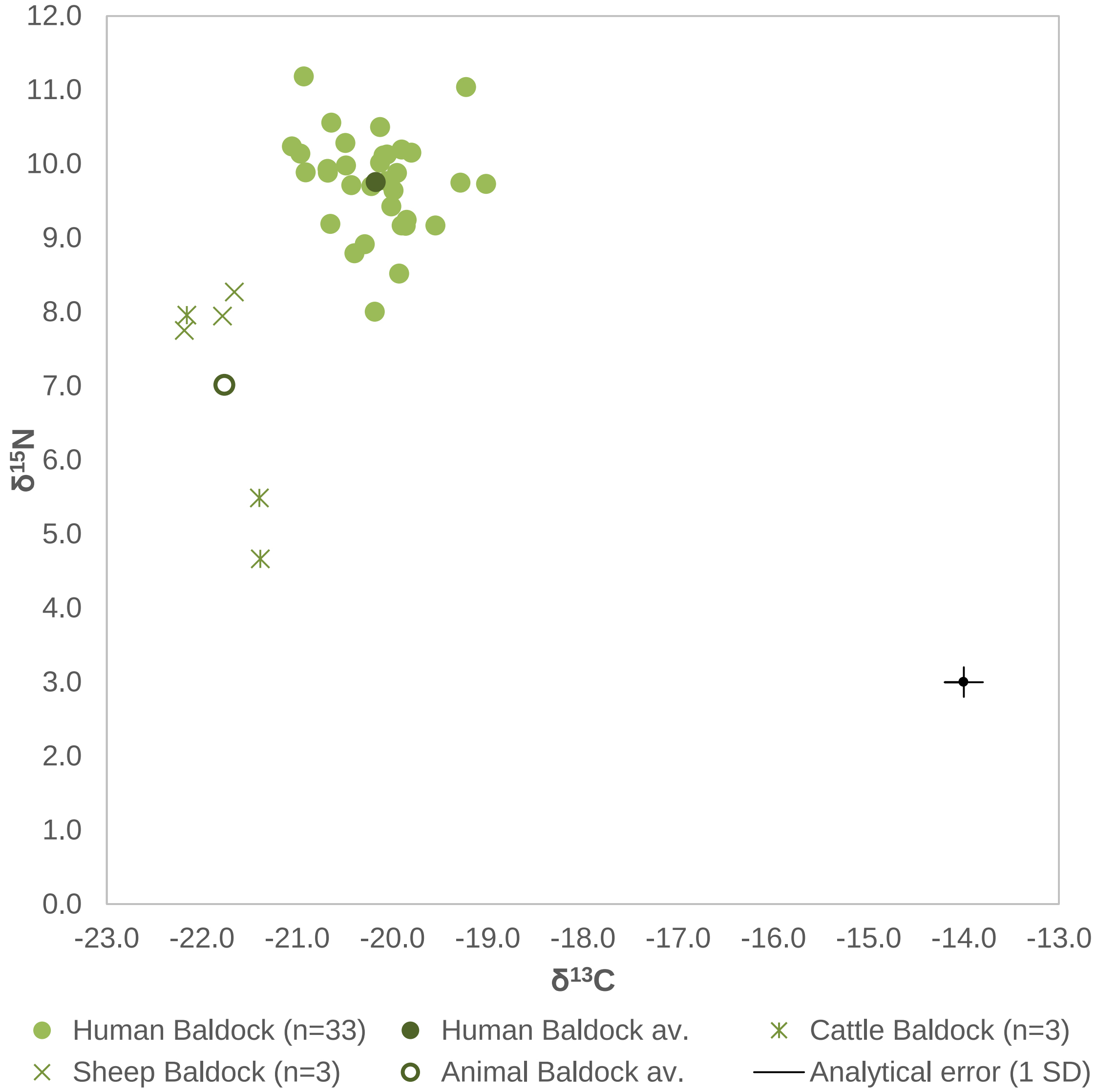


Figure 101: Isotope data from human and animal archaeological samples from Roman Baldock

B.5.11.1.2 Roman Catalan stable isotope results

The six faunal remains from Santa Caterina were found at the same location as and were considered contemporaneous to the human remains. Two adult cattle, one goat, one pig, one adult sheep and one sub-adult (SA) sheep were analysed (Table 70) to prove a baseline for the interpretation of the human isotope results.

The results obtained from the faunal remains from Santa Caterina are very similar to the results obtained from other contemporary Roman sites from around the Mediterranean basin (Appendix 5.2). The only surprising value is the nitrogen from the lamb (137-05-81-2) which was expected to be higher compared to the adult sheep but in fact falls within the ranges observed for the adult individuals. This could suggest that the lamb had already been weaned and was being fed on adult fodder.

Table 70: Isotope data for the animal samples from Roman Santa Caterina

ID	Species	δ^{15}N‰	δ^{13}C‰	Amt%N	Amt%C	C/N
137-05-UE 100	Goat	3.8	-20.1	16.7	45.8	3.2
018-01-450	Cattle	3.8	-20.1	14.8	40.8	3.2
137-05-123	Cattle	2.6	-22.0	13.6	37.5	3.2
018-01-456	Pig	3.7	-20.1	13.8	38.3	3.2
137-05-81-1	Sheep	7.9	-19.6	14.4	39.7	3.2
137-05-81-2	Sheep SA	6.7	-19.3	13.1	36.8	3.3
Average		**4.8**	**-20.2**			

The nitrogen isotope values obtained from the 41 individuals from Santa Caterina range between 8.6‰ and 11.0‰, with an average of 9.9%, and the carbon isotope values range from -20.2‰ and -18.6‰ with an average of -19.2‰ (Table 71). These values suggest that the Roman Catalan sample mostly followed a terrestrial diet and the small ranges in both, carbon and nitrogen isotopic values, indicate that most individuals subscribed to a highly similar diet or followed different but isotopically equivalent diets. In this site, however, there is one individual (002-00-706) whose nitrogen isotope value falls within the normal range (9.7‰) but the carbon value, at -16.2‰ is significantly higher compared to the sample average (shaded in Table 71). This individual was assessed as male, with an estimated age of 47.5 (age range: 24.0 – 83.2 years) and with no pathologies other than four events of linear enamel hypoplasia between, approximately, 4.5 and 6.5 years of age.

Comparing the human results to the animal baseline obtained from the same site and accepting the 3-5‰ increment between steps of the food chain, the sample from Barcelona seem to have been either heavily reliant on sheep meat (average $\delta^{15}N$ difference: 2.6‰) or have followed a more varied diet containing cattle, pig or goat meat (average $\delta^{15}N$ difference: 6.4‰) possibly supplemented with marine resources (Figure 102).

Table 71: Isotope data for the human samples from Santa Roman Caterina

Individual	$\delta^{15}N$‰	$\delta^{13}C$‰	Amt%N	Amt%C	C/N
162-06 UF6	9.8	-18.9	15.5	43.6	3.3
201-05 UF01	10.1	-19.7	15.2	42.9	3.3
201-05 UF19	10.0	-19.6	17.0	46.6	3.2
201-05 UF28	9.4	-19.6	16.2	45.1	3.2
001-01 754	9.1	-19.0	12.6	34.8	3.2
002-00 709	10.2	-18.8	15.7	43.4	3.2
001-01-748	9.3	-20.2	12.1	33.7	3.2
001-01-755	9.6	-18.8	12.3	34.2	3.2
001-01-756	8.6	-19.3	11.5	31.9	3.2
001-01-758	10.2	-19.1	10.2	27.9	3.2
002-00-706	9.7	-16.2	12.8	35.2	3.2
002-00-707	9.7	-19.3	12.7	35.0	3.2
002-00-708	9.7	-19.2	13.9	38.2	3.2
002-00-710	8.8	-19.1	13.4	37.1	3.2
002--00-719	9.9	-19.5	13.5	37.2	3.2
002--00-721	9.4	-19.4	13.2	36.6	3.2
002--00-725	9.8	-19.3	13.7	37.6	3.2
002--00-727	10.2	-19.3	14.3	40.2	3.3
002--00-729	9.9	-19.6	13.4	37.3	3.3
002--00-731	9.8	-19.4	12.6	34.7	3.2
002--00-732	9.7	-19.3	12.7	35.1	3.2
002--00-733	9.9	-19.6	13.4	37.3	3.2
010-04-T14	10.3	-19.6	12.9	35.7	3.2
010-04-T15	9.8	-19.9	11.2	31.2	3.2
010-04-T18	9.2	-20.0	10.4	29.7	3.3
010-04-T3	10.5	-20.0	12.7	35.2	3.2
018-01-T15	8.6	-19.6	12.5	35.0	3.3
018-01-T25	8.8	-19.6	12.2	34.4	3.3
018-01-T29	9.8	-19.6	12.0	33.3	3.2
072-86-A1.124	10.1	-18.9	13.1	36.2	3.2
072-86-B1.119	10.1	-19.1	11.5	32.2	3.3
072-86-B1.123	10.1	-19.1	12.9	35.7	3.2
072-86-B1.148	9.5	-19.2	12.9	35.8	3.2
072-86-B1.93	10.3	-19.2	10.9	30.2	3.2
072-86-B2.50	11.1	-18.7	13.2	36.6	3.2
072-86-B2.57	9.9	-19.3	13.3	36.8	3.2
072-86-B2.62	10.9	-18.6	13.6	37.5	3.2
072-86-B3.21	10.6	-19.1	13.1	36.8	3.3
072-86-B3.59	11.1	-18.8	13.2	37.3	3.3
072-86-B3.67	10.6	-19.0	12.7	35.9	3.3
072-86-B3.87	10.7	-19.0	13.5	37.4	3.2
Average	**9.9**	**-19.2**			

Outlier indicated with grey shadding

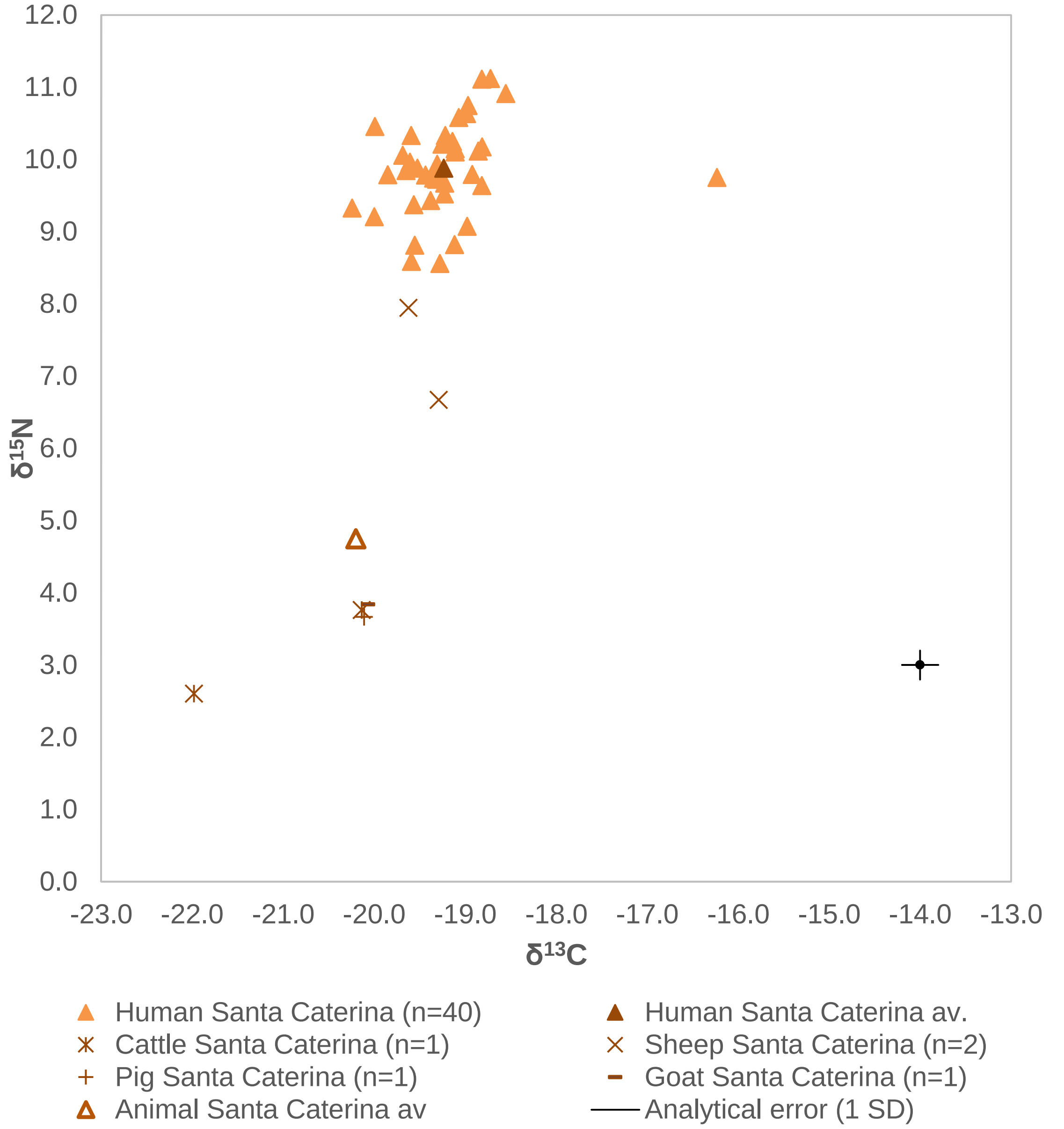


Figure 102: Isotope data from human and animal archaeological samples from Santa Caterina

B.5.11.1.3 Comparison between Romano-British and Roman Catalan stable isotope results

When combined, the data obtained from the Catalan and British individuals cluster together in one region suggesting that these samples could have followed similar terrestrial-based diet (Figure 103). In fact, the average $\delta^{15}N$ values are remarkably similar, 9.9‰ for the Catalan and 9.8‰ for the English sample and the average $\delta^{13}C$ value of the Catalan seems to be higher only by 1‰ compared to the English value. However the English and Catalan animal baseline is not similar. The isotope results obtained from Baldock's faunal remains show higher nitrogen and lower carbon values compared to the fauna from Santa Caterina ($\delta^{15}N$: 7.0‰ and 4.7‰; $\delta^{13}C$: -21.8‰ and -20.2‰ respectively) (Figure 103). This suggest that while the human isotope data is the same, the diet that these two populations followed was possibly different as the Romano-British possibly relied heavily on terrestrial resources while the Catalan population had a more varied diet which would have included marine and terrestrial resources.

It is also worth noting the 1.6‰ difference in the average carbon value in the faunal remains from Baldock ($\delta^{13}C$: -21.8‰) and Santa Caterina ($\delta^{13}C$: -20.2‰). This notable difference suggest that probably even the animals were fed differently; with the animals from Santa Caterina being partially fed on C_4 plants. These results also suggest that the higher carbon values observed in the Catalan human remains compared to the English one are probably related to the indirect incorporation of C_4 plants in the diet as a result of the consumption of animal products with higher carbon signature. Nevertheless in the following Chapter (B.7), these results will be contextualised with the historic documentary sources and other archaeological data to elucidate whether these samples did follow or not a similar diet.

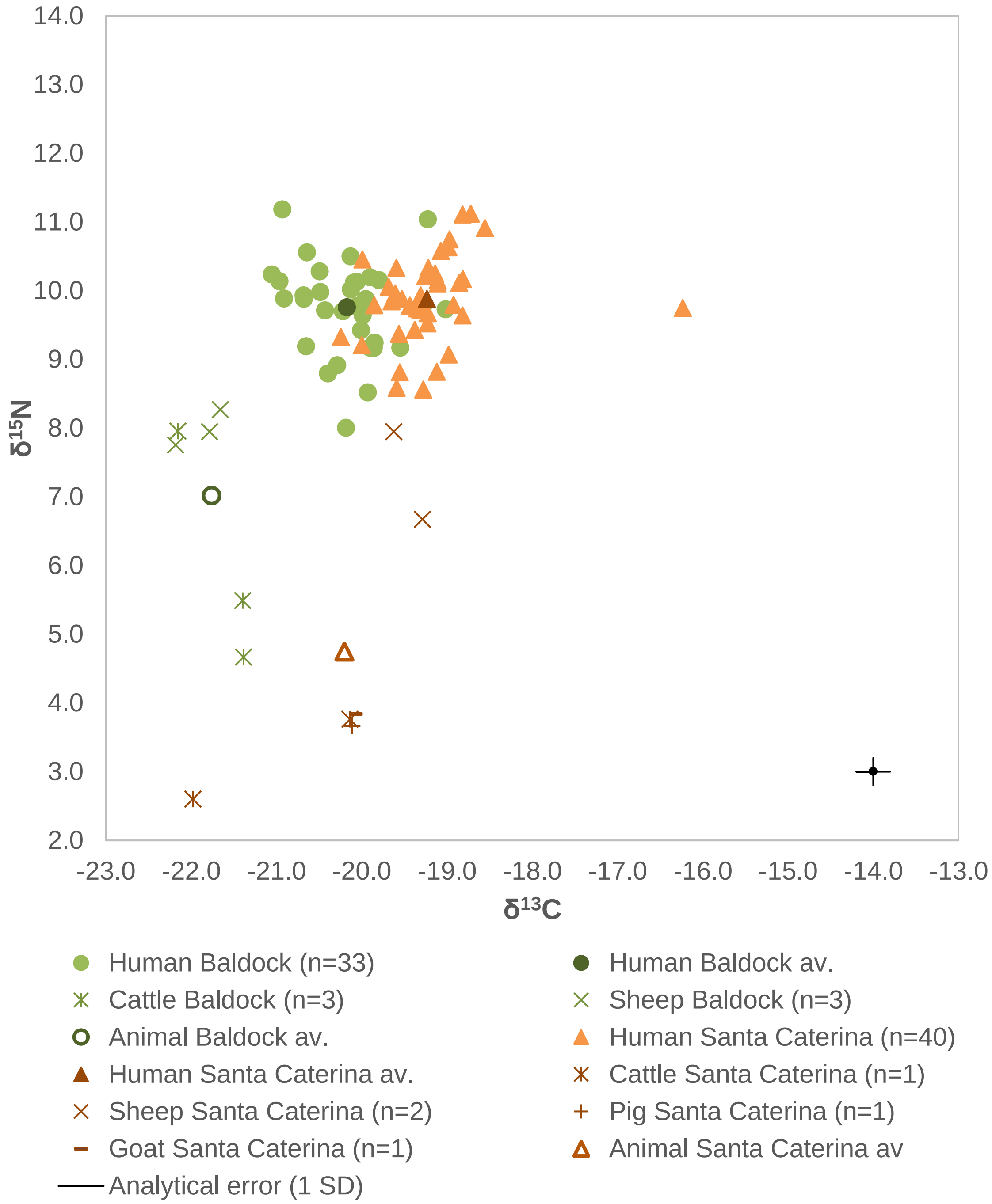


Figure 103: Isotope data of the human remains from Baldock and Santa Caterina

B.5.11.2 Correlation between stable isotope results and DISH status

For this section, due to the small size of the sample, the individuals with and without DISH from both samples have been combined to investigate whether there is any relationship between DISH status and isotope signature. The stable isotope signature for all the individuals with DISH cluster very close together (Figure 104, Table 72) suggesting that there are no significant differences in the diet of these individuals nor link between severity of the disease and type of diet as deduced by stable isotope analysis.

Table 72: Isotope data for the individuals with DISH

Individual	**δ^{15}N‰**	**δ^{13}C‰**	DISH
002–00–727	10.2	-19.3	1
001-01 754	9.1	-19.0	1
BAL 1072	9.9	-20.0	1
BAL 1374	9.4	-20.0	2
BAL 1049	9.7	-19.3	2
BAL 2225	9.7	-20.2	2
001–01–756	8.6	-19.3	2
BAL 1122	10.1	-20.1	4
BAL F92	10.1	-20.1	4
Average	**9.6**	**-19.7**	

Similarly, when the isotope signatures from the individuals with DISH are compared to that of the individuals without DISH, there does not seem to be any difference in the carbon or the nitrogen ratios. This could be related to the small number of individuals with DISH in the sample or to the possibility the individuals with and without DISH followed either the same diet or isotopically similar diets.

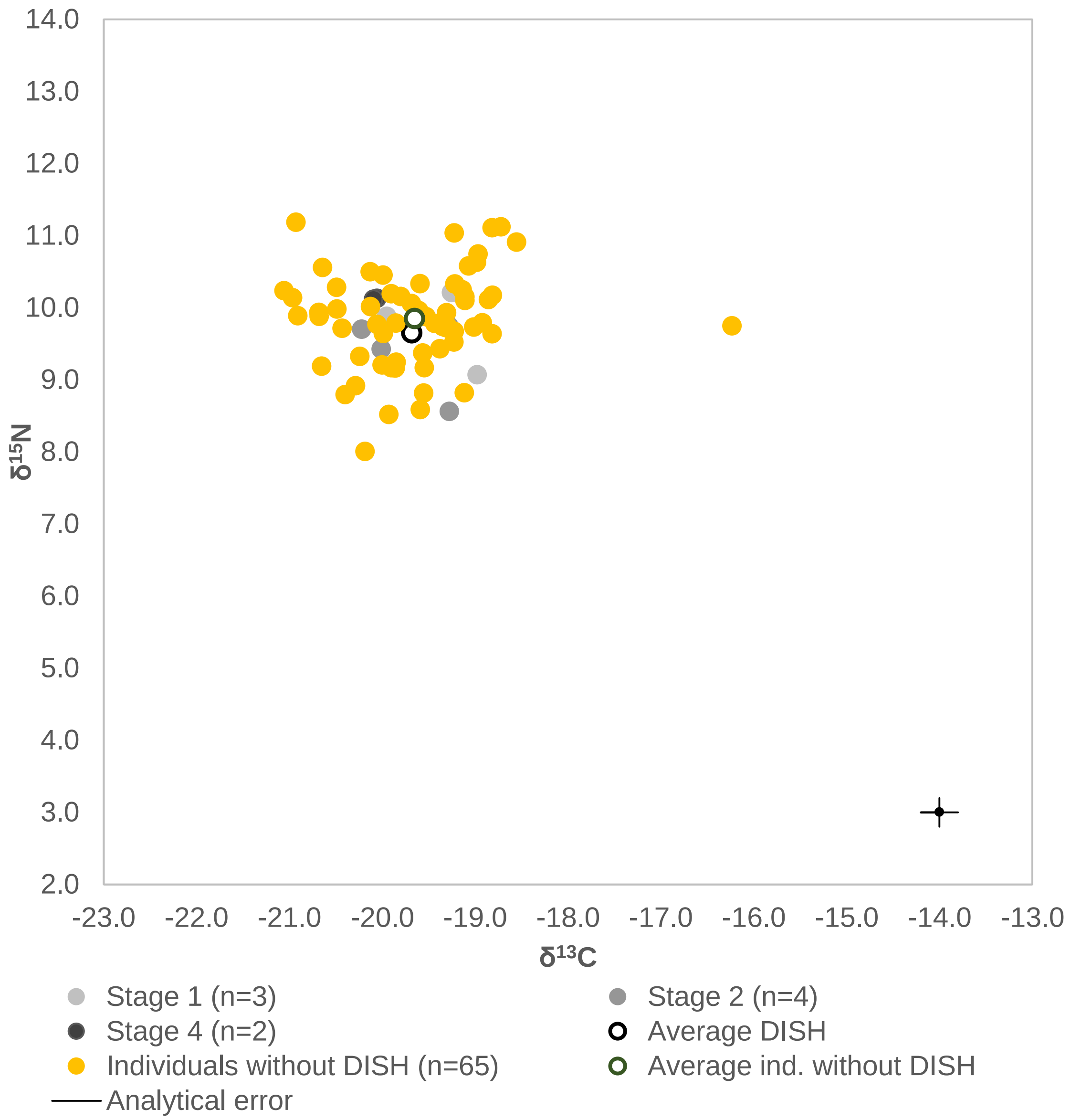


Figure 104: Comparison of the stable isotope results between individuals with and without DISH

B.6 DISCUSSION

In this chapter, the results obtained from the macroscopic as well as the stable isotope analysis of the Catalan and English populations will be contextualised and compared to other previously published data. The structure of this chapter will follow that of the results thus, first, the diachronic analysis and regional prevalence of DISH in English and Catalan populations will be discussed. The following sections will evaluate the distribution of the spinal lesions, the relationship between the spinal lesions of DISH and discarthrosis and between the spinal and the extra-spinal manifestations of DISH. Finally, the results from the analysis of the co-morbidity of DISH other nutrition and metabolism-related conditions will be discussed.

B.6.1 Limitations

The results will be discussed within the frame of other archaeological and clinical studies where the prevalence of DISH has been reported. However there are several difficulties when attempting to compare the results obtained from archaeological human remains to the wider literature. Firstly, there is a considerable lack of published data specifically dealing with DISH thus all the available regions and types of populations (i.e. lay and monastic populations) will be considered as valid.

Secondly, to the author’s best knowledge, this is the first time that an exhaustive demographic profile of DISH has been drawn. In most published studies, either all the adults have been grouped together or a single threshold (e.g. over 40, over 50 or over 64 years of age) was imposed as an inclusion criteria (Table 14 in

Section B.1.1). In this case, the best efforts will be made to try to discuss the results at a comparable level taking into account the different age categories that have been used in the different studies.

Thirdly, if the diagnostic criteria is reported, most of these studies used Resnick and Niwayama's (1976) criteria for clinical patients, Rogers, et al. (1985), Rogers and Waldron (1995) or a modified Utsinger (1985) criteria. As it has been previously discussed, the results obtained from these different methods are not directly comparable (Diederichs et al. 2011; van der Merwe et al. 2012). Nevertheless, all these criteria require at least four vertebrae involved in the ankylosis to issue a positive diagnosis and at least two to consider a possible diagnosis. As the criteria utilised in here includes significantly earlier stages of DISH development and only stage 4 coincides with the widely used criteria, when comparing with previously published data, only the prevalence of advanced DISH (i.e. stages 3 and 4) will be considered.

And finally, while there are several studies investigating the prevalence of DISH in a specific population (Table 14 in Section B.1.1), the majority of papers related to DISH in the Iberian Peninsula and Mediterranean are either case studies (De la Rúa and Orúe 1992; Reale et al. 1999; Subirana i Domènech et al. 2002; Giuffra et al. 2010; Márquez-Grant et al. 2012) or the sample size is too small to allow any comparison with other studies (Martínez Diez and Martínez Flórez 2013). The lack of published data from contemporary sites from the same region make it difficult to evaluate the results obtained here thus the Catalan results will be compared against the contemporary data obtained from other European and international studies.

B.6.2 DISH in Roman populations

In the Romano-British sample (n=74) the overall prevalence of DISH was of 9.5%, that of stage 1 is of 1.4% and stage 2 and 3 of 4.1% each. If only the advanced DISH stages are considered, the prevalence of DISH in this sample is 4.1%. In contrast, the overall prevalence of DISH in the Roman Catalan sample is 6.9%, (n=87). All cases found were at stage 1 or 2 thus when comparing against other populations, the prevalence of DISH in Roman Catalan sample is, effectively, 0% (Sections B.5.2 and B.5.3).

Table 73: Summary table of the prevalence of DISH in Roman populations

Reference	Site	n.	DISH (%)[1]
This project	Romano-British	74	4.1
This project	Roman Catalan	87	0.0
Rogers et al.(1985)	Ilchester (Som.)	81	0.0

[1]Considering stages 3 and 4.

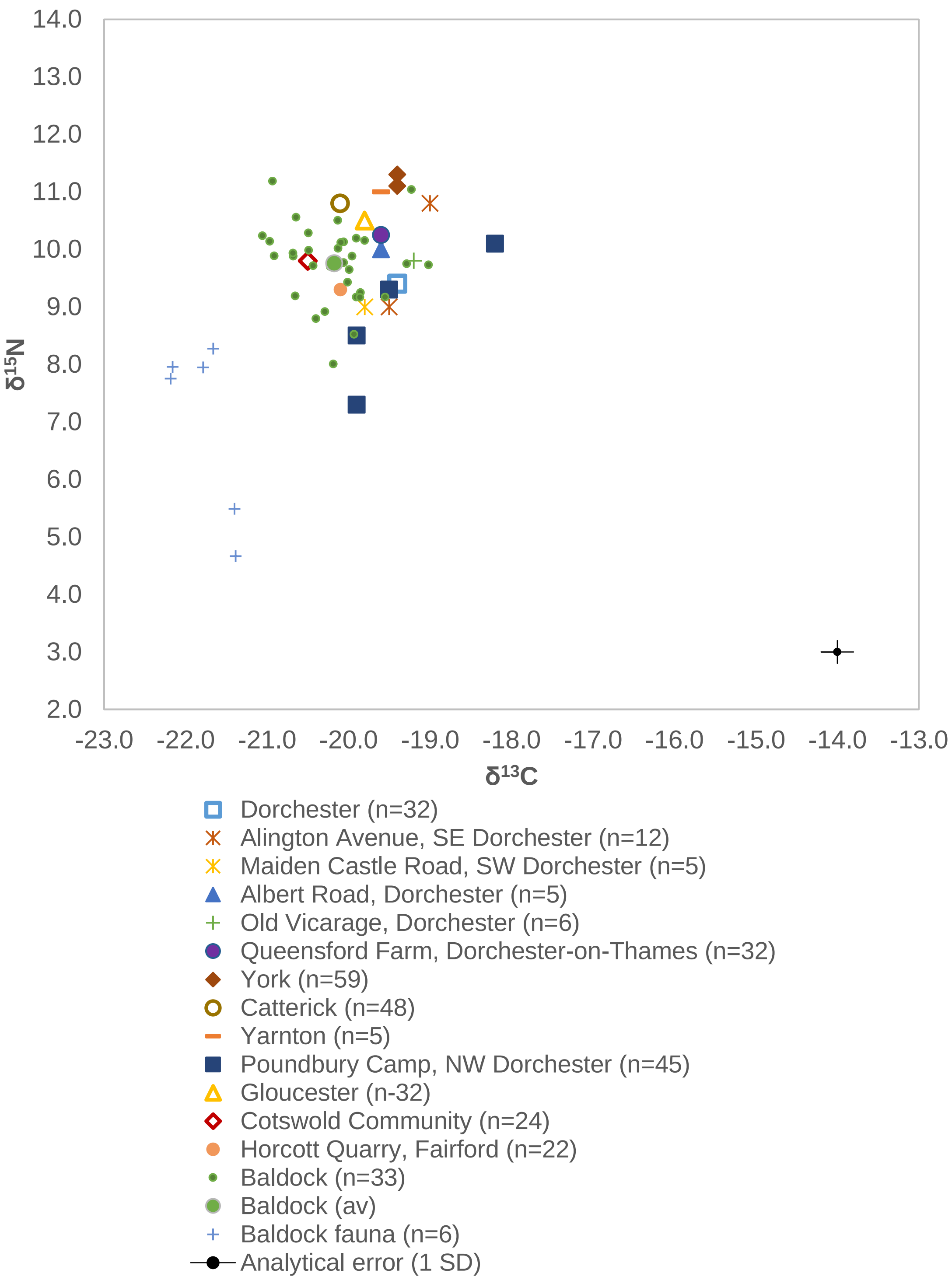
Rogers et al. (1985) considered a positive diagnosis of DISH when ankylosis was present between two or more adjacent vertebrae; this threshold coincides with the herein described stage 3 of DISH. Therefore the results obtained from the Catalan sample mirror those obtained from Ilchester (Somerset). The Romano-British sample from this study however, show a slightly higher prevalence of DISH than the previously reported in the Romano-British period (Table 73) however this difference is not statistically significant. Thus, overall, these results correspond with the original expectations that the prevalence of DISH in the Roman period would be very low.

The contextualisation of these results with the dietary characteristics of the English and Mediterranean populations and the isotope data obtained from

Baldock and Santa Caterina suggests that the different dietary patterns suggested by documentary resources and archaeological data are not reflected in a significant difference in the prevalence of DISH between these two populations. The Romano-British diet varied depending on the type and location of settlement and the retention of Late Iron Age dietary patterns, mainly in rural settlements, was a commonly phenomenon. During the Roman period, Baldock was a village with urban-settlement characteristics and with a significant presence of agricultural activities (Section B.3.2.2.1). This makes it complicated to theoretically define the diet its inhabitants might have followed, however it is very possible that the diet reflected this dual character; mixing new acquired tastes and retained Late Iron Age practices. Following the patterns observed in the rest of the region, wheat and possibly spelt were the dietary staples of the population, cattle was probably the dominant meat (reflecting the “Germanic or Gallic patterns” imported by the soldiers who arrived with the conquest) and fish from the southern North Sea was possibly also consumed (Locker 2007) (Section B.4.1.1 and Appendix 5.1.1).

The carbon isotope signature of the individuals and the animal baseline from Baldock is comparable to all the sites referred to in section B.4.1.1 suggesting a C_3 plant-based diet. Based on the analysed animal baseline, it seems the individuals from Baldock followed a terrestrial C_3-plant based diet (Figure 101 in Section B.5.11.1). The nitrogen values from the individuals from Baldock are similar to those obtained from other Romano-British sites like Albert Road, Cotswold Community, Dorchester, Horcott Quarry, Old Vicarage, the Late Romano-British individuals from the main cemetery and those buried in the mausolea from Poundbury Camp, Queensford Farm and Dorchester (Richards et al. 1998; Fuller et al. 2006; Redfern et al. 2010; Cheung et al. 2012) (Figure 105). As noted in the sample from Santa Caterina, nitrogen values show an inter-individual variability indicating variable reliance on marine resources. In fact, the average human faunal-carbon offset of 1.6‰ could suggest that, at least some of the individuals of this population (those with an offset $\delta^{13}C$ of over 2‰), consumed marine or anadromous fish in a regular manner albeit possibly in small quantities (Müldner and Richards 2007b; Chenery et al. 2010). Archaeological and documentary sources suggest that the Romano-British population consumed freshwater and marine resources, however if fish was not a significant source of protein, the strong terrestrial signal observed in the individuals from Baldock is, in fact, also masking the fish signature (Redfern et al. 2010).

Nevertheless, the majority of protein was from terrestrial origin and while it is not clear *how much* meat these individuals consumed, at least the Roman soldiers consumed meat daily (Davies 1971: 126). It is therefore possible that, even in small quantities, meat was regularly consumed by the Romano-British population; a dietary pattern that may have influenced the prevalence of DISH.



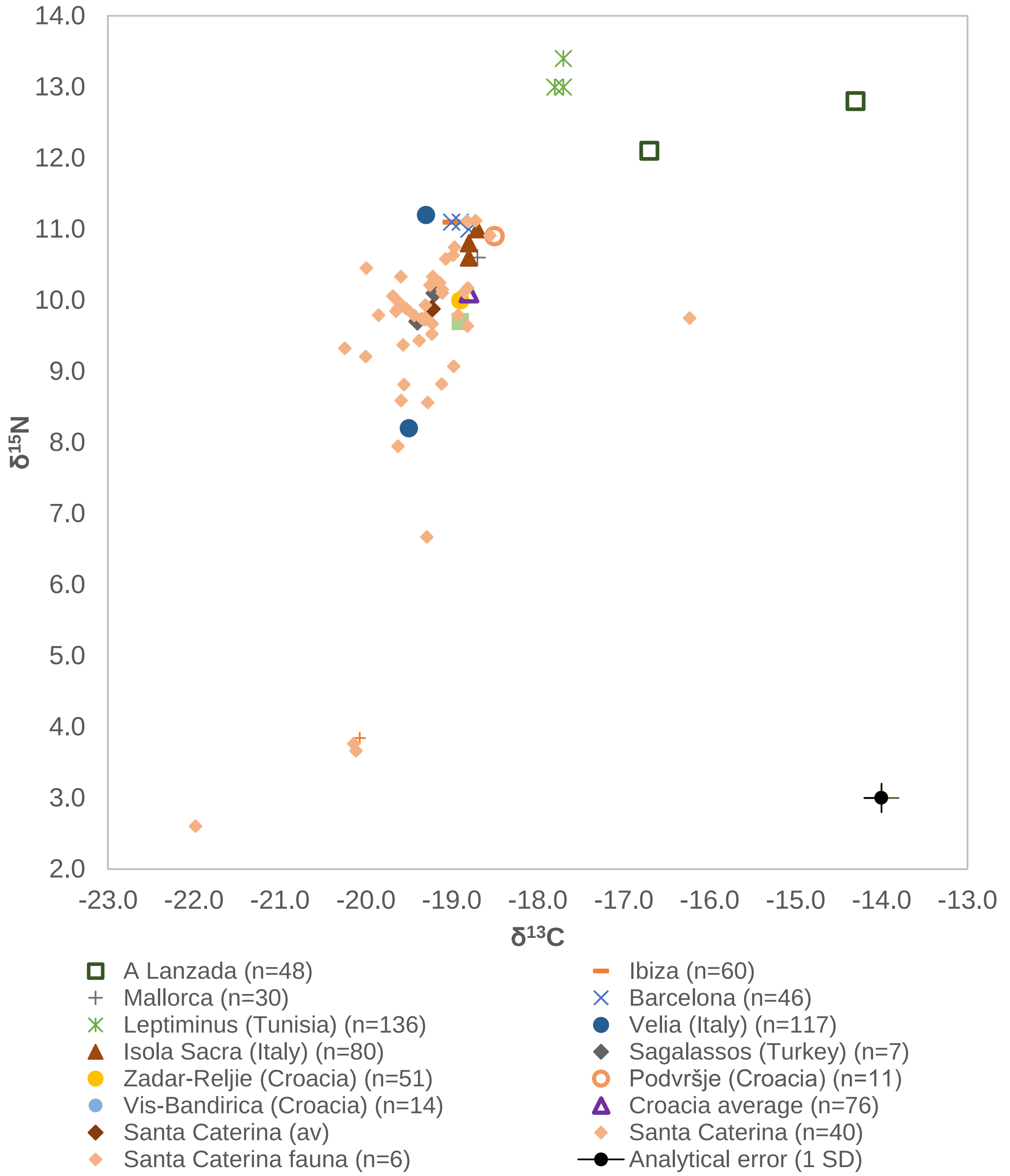
Graph by author. Data from: Richards et al. (1998), Fuller et al. (2006), Müldner and Richard (2007b), Redfern et al. (2010), Chenery et al. (2011) and Cheung et al. (2012). Data represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample

Figure 105: Average isotope values for Romano-British sites including Baldock's human and faunal data

Considering their status in the Roman Empire, Tarraco (*Colonia Iulia Triumphalis Tarraco*) was a very important harbour and Barcelona (*Colonia Iulia Augusta Fauentia Paterna Barcino*) was, albeit smaller than Tarraco, still a Roman colony with seafaring activities (Rissech et al. 2016). The title of *colonia* for both cities suggest that they had possibly been deliberately created by the Roman government and settled by Roman or Latin citizens (Kulikowski 2005: 34) thus most of the population living in these urban centres probably followed a mainly vegetarian diet based on wine, olive oil and cereals, vegetable and fruit and supplemented with pig and, possibly, readily available marine resources (see Section B.4.2.1 and Appendix 5.2.1) (Gómez i Pallarès 1996; Garnsey 1999; King 1999; Alonso Martínez 2000; Prowse et al. 2004; Ejstrud 2006; Faas 2006; Colominas 2017).

Stable isotope data from the human and animal remains from Santa Caterina suggest also a Roman diet which was similar to that followed by the Hellenistic population from Sagalassos and the Roman community from Croatia (Fuller et al. 2012; Lightfoot et al. 2012). However the average nitrogen value for Santa Caterina appears marginally lower when compared to a second cluster of data from Carrer Ample (Barcelona), Mallorca, Ibiza, the Italian site of Isola Sacra and II from Velia (Garcia et al. 2004; Prowse et al. 2004; Prowse et al. 2005; Craig et al. 2009; Fuller et al. 2010; Rissech et al. 2016) (Figure 106). Compared to the animal baseline obtained from the same site and accepting the 3-5‰ enrichment between steps within the food chain, the diet of the individuals from Barcelona seem to have been based on cattle and pig meat supplemented with marine resources, thus agreeing with the zooarchaeological data and the contemporary documentary sources. The significant inter-personal variation in regards to the nitrogen values (range: 8.6 – 11.1‰) possibly indicates that the consumption of marine resources varied remarkably between individuals. Nevertheless this almost vegetarian diet with small supplements of marine and terrestrial protein should, theoretically, lead to low prevalence of DISH and therefore concurs with the findings regarding the prevalence of DISH, as the Roman Catalan sample showed the lowest prevalence of advanced DISH of all samples evaluated.

Individual 002-00-706, whose nitrogen and carbon isotope value were 9.7‰ and -16.2‰ respectively, appeared with significantly higher carbon values compared to the population average and outside the abovementioned cluster of populations. In fact, while the nitrogen values still suggest a mainly terrestrial diet, the carbon values resemble more those observed in the individuals from A Lanzada (northwest of Spain) which was interpreted as suggestive of heavy reliance on C_4 resources, probably millet (López-Costas and Müldner 2016). Millet (C_4 plant) has been direct consumed or, like *spartina sp.,* used as fodder in the region of Catalonia since the 2nd millennium BC (Alonso Martínez 2000; Tafuri et al. 2009; López-Costas and Müldner 2016). The fact that this is the only outlier could suggest that this male individual came from an area where C_4 plants were more widely available. Alternatively, this individual was local and simply had a diet more reliant in this type of resources. It is not possible, for now, evaluate these hypothesis as mobility stable isotope such as strontium, oxygen and possibly lead would need to be applied.



Graph by author. Data from: García et al. (2004), Prowse et al. (2004, 2005), Craig et al. (2009), Keenleyside et al. (2009), Fuller et al. (2010, 2012), Lightfoot et al. (2012), López-Costas and Müldner (2016) and Rissech et al. (2016). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample

Figure 106: Average isotope values for Iberian and Mediterranean sites including Santa Caterina's human and faunal data

DISH has been consistently related to diet and metabolic imbalances (see section A.4.5) thus it was considered that the significant difference, in prevalence and in the stages of development found in the individuals from the Roman Catalan and the Romano-British population would be somehow related to different dietary patterns. Isotope data suggest that the Romano-British individuals possibly followed a terrestrial C_3-based diet while the Catalan individuals seem to have included terrestrial and marine products in their diet however it is possible that the Catalan population ate less meat and fish as these products were considered supplements (Craig et al. 2009). If true, this would probably have reduced the probability of developing DISH compared to the English sample as, while it is not clear how reliant on meat were the individuals from Roman Britain, the more militarised diet following a Germanic and Gallic pattern as opposed to the "Roman" diet could mean that their intake of meat was greater (Davies 1971). Interestingly, while the English sample seems to have a marginally higher prevalence of DISH, this difference is not statistically significant. This could suggest that an underlying predisposition for certain populations to develop this condition. However until the Roman reliance on meat and the possible genetic predisposition of DISH are properly comprehended, this question will remain open however the possible genetic factor will be further explored in section B.6.7.

B.6.3 DISH in early medieval populations

The 19 individuals diagnosed with DISH (16.4%) in the Anglo-Saxon population of Raunds suggests an increase in the prevalence of DISH compared to the Roman period. However as only one individual showed changes classified as stage 3 the prevalence of advanced DISH is of 0.9%. Likewise, the prevalence of DISH in the early medieval Catalan site also points at an increase compared to the Roman Catalan sites with an overall prevalence of 12.3%; however if only stages 3 and 4 are considered, then the prevalence drops to 3.1% (sections B.5.2 and B.5.3).

Table 74: Summary table of the prevalence of DISH in early medieval populations

Reference	Site	n.	DISH (%)[1]
This project	Raunds	116	0.9
This project	E. med. Catalan	65	1.5
Rogers et al. (1985)	St. Peter's Church	121	2.0
Kramar et al. (1990)	Sion Sous-le-Scex	27	3.7

[1]Considering stages 3 and 4.

The prevalence of advanced DISH in the early medieval English and Catalan samples is comparable to those obtained from the Anglo-Saxon site of St. Peter's Church in Barton-on-Humber (Rogers et al. 1985) and was slightly lower than that reported for the early medieval Swiss site of Sion Sous-le-Scex in Valais (Kramar et al. 1990) (Table 74).

Returning to the populations studied in this project the increase in the prevalence of DISH in both regions is suprising but not unexpected. Archaeological and isotope data from the Anglo-Saxon suggests that the majority of the population continued to follow a terrestrial C_3 plants based diet regularly supplemented with meat possibly from cattle and sheep/goat. Fish consumption varied possibly depending on the proximity to the source (Privat et al. 2002; Müldner and Richards 2007b; Mays and Beavan 2012). However the variability observed in the results obtained from different sites possibly reflect social, regional and ethnic-related dietary differences (Pearson 1997) (see section B.4.1.2 and Appendix 5.1.2).

Similarly to the early medieval English diet, according to documentary, zooarchaeological and archaeobotanical records and isotope data the Catalan early medieval diet seems to have been also dominated by C_3 plants, with a variable input of C_4 plants, consumed directly or fed to the domesticates. Cattle and sheep or goat were the preferred types of meat and there is very little, if any, references to marine or freshwater resources (Lightfoot et al. 2012; Sirignano et al. 2014; García-Collado 2016) despite the fact that the Christian influence in western Europe promoted the consumption of fish in fasting days (Hoffmann 2005). In contrast to the Roman Catalan diet, the Carolingian population seems to have been eminently meat eater (Fàbrega 2016: 46) (see section B.4.2.2 and Appendix 5.2.2).

While it is not possible to known what “eminently meat eater” or “regularly included meat” diet exactly means in terms of how much meat was actually eaten, it is nonetheless possible that both early medieval populations relied more heavily on meat than their respective Roman period populations. Given the previously mentioned relationship between DISH and a range of clinically-identified metabolic imbalances (see section A.1.3.1) and with a rich high-protein diet (Waldron 1985; Jankauskas 2003; Giuffra et al. 2010), this shift in the dietary pattern should have led to a clear increase in the prevalence of DISH in the populations studied here. However while there is a trend suggesting an increase in the prevalence from Roman to early medieval populations, this is not statistically significant. This results then reinforce those observed for the Roman populations where it seems that diet is not the only factor influencing the development of DISH. Is it then possible for this observable shift to be also related to the migration of Germanic people to the British Isles and Catalan lands?

The scale of the Anglo-Saxon migration is still being contested (Moreland 2000) and it has traditionally been the view that the new Visigothic population represented a very small percentage (possibly less than 2%) of the native Catalan population. It was mainly the high military and auxiliary societal segments that were replaced (Vives i Balmaña 1989). Nevertheless, to assume that the migrant population had a strong biological influence over the native population means to assume that, first, the size of the migration was big enough to influence the genetic make-up of the native population and, second, that this new population had a stronger predisposition to develop DISH. However, if the evidence indicating that the choice of diagnostic criteria can influence the calculated prevalence of DISH is momentarily sided, while it seems that some past and modern Eastern and Central European populations might have had a higher prevalence of DISH compared to the early medieval samples herein analysed, there is a significant variability in the prevalence rates published in the different studies (Table 75). Thus it seems unlikely that the increase in the prevalence of DISH between the Roman Catalan and the Romano-British was driven by a mass migration with a significantly greater predisposition to suffer DISH.

Table 75: Prevalence of DISH in Central and Eastern European archaeological and modern populations

Type	Author	Location	Prevalence (%)[a]
Archaeological	Jankauskas et al. (2003)	Lithuania	9.1±2.9
	Kramar et al. (1990)	Switzerland	3.7
	Maat et al. (1995)	Holland	M: 10.3; F: 3
Modern	Julkunen et al. (1971)	Finland	M: 3.5; F: 2.2
	Kiss et al. (1997)	Hungary	M: 5.8; F: 1.3
	Kiss et al. (2002a)	Hungary	M: 27.3; F: 12.8

[a] Equivalent to stages 3 and 4 of the criteria defined in Table 18, Section B.2.3.3

Contrastingly, the migration could have had a more "cultural" influence over the receiving population. For example, it seems the Visigoths had a great influence in the Catalan political and social structure (Vives i Balmaña 1989) and during the Anglo-Saxon period, burial practice changes as well as historical, anthropological, environmental and linguistic evidence reflect this cultural influence (Scull 1993). Furthermore the shift in the dietary habits from the Roman to the early medieval periods would also be included in these "cultural" shifts that could have been brought by the newcomers independently of their number.

In sum, the diet of the early medieval populations seem to have included a higher percentage of meat compared to the previous period however the prevalence of DISH does not seem to be significantly higher compared to the previous Roman populations. The high variability in the prevalence of DISH in the Central and Eastern European communities makes it complicated to assert that the newcomers showed a significantly greater predisposition of DISH compared to the Roman populations. As the demographic profiles of Roman and early medieval Catalan and English populations are similar, it is therefore likely that the observable but not significant increase in the prevalence of DISH observed for the early medieval Catalan and the Anglo-Saxon population is related to a variety of factors including dietary habits. It is also possible that while documentary and archaeological resources suggest a significant change in the diet, the shift might have been less drastic than originally hypothesised.

B.6.4 DISH in late medieval populations

The prevalence of DISH in the late medieval English and Catalan samples is slightly lower compared to the early medieval but higher than the Roman samples. In this case, prevalence of advanced DISH the late medieval English sample is of 4.7% and in the late medieval Catalan sample is 3.4%. It is notable that while it was expected that the overall prevalence of DISH in the late medieval period is lower than in the early medieval one however, it was not originally foreseen that the prevalence of advanced stages would be, in fact, maintained (Figure 88 in Section 5.5).

Table 76: Summary table of the prevalence of DISH in late medieval populations

Reference	Site	n.	DISH (%)[1]
This project	Fishergate House	64	4.7
This project	L. med. Catalan	89	3.4
Rogers et al. (1985)	Med. English	303	3.7
Cunha (1993)	Portugal	44	11.4[2]
Maat et al. (1995)	Amsterdam	179	14.5
Jankauskas (2003)	Lithuania	316	13.3±1.9

[1]Considering stages 3 and 4. [2]Prevalence of definite DISH: 11.4%; prevalence of possible DISH: 34% (Cunha 1993)

The prevalence data obtained from late medieval populations is very variable (Table 76). The prevalence rate reported for the English medieval population (Rogers et al. 1985) is similar to the ones found in the late medieval English and

Catalan samples. However the prevalence rates reported from the 2nd millennium AD Lithuanian population, from the 12th to 15th centuries Portuguese population and from the churchyard of a Minorite monastery from the late medieval Dordrecht (modern Amsterdam, Holland) are significantly higher (Cunha 1993; Maat et al. 1995; Jankauskas 2003). It is worth noting that in the Lithuanian population, the prevalence was calculated taking into account the wealthy, the lay and the poor communities with the first one showing a significantly higher prevalence of DISH (Jankauskas 2003). Likewise, the high prevalence obtained from the Portuguese population was argued to be related to the middle to high status of the population of Coimbra as well as the advanced age of most of the individuals (Cunha 1993). Similarly to the late medieval city of Dordrecht which was also a prosperous commercial centre of The Low Countries (Maat et al. 1995). This analysis then further stresses the need to consider age at death as well as status diet of the population when comparing their prevalence of DISH.

The late medieval diet in Catalonia and in Britain was significantly influenced by the regime established by the ecclesiastic calendar. Archaeological and isotope data as well as documentary resources suggest that the late medieval English diet was based on bread and ale supplemented with vegetables, dairy, eggs and fish. Meat was only allowed on non-fasting days and its consumption increased after the Black Death pandemic. The most significant shift in the late medieval diet, compared to the previous one, is the increased consumption of marine and, possibly, freshwater fish (Dyer 1988: 92; Mays 1997; Barrett et al. 2004; Müldner and Richards 2005; Serjeantson and Woolgar 2006: 127; Müldner and Richards 2007a; Müldner and Richards 2007b; Spencer 2011: 83, 88, 92) (see chapter

B.4.1.3 and B.4.2.3 and Appendices 5.1.3 and 5.2.3). Thus it is possible that the late medieval populations ate more fish and meat than the Romano-British populations and more fish but less meat than the early medieval population. If that is true, the intermediate prevalence of DISH found in this population when all the stages of the disease are taken into account (late medieval: 12.5%; Romano-British: 9.0%; early medieval: 19%) suggesting that the dietary changes observed across periods may have influenced the development of the disease.

In Catalonia, on fasting days, terrestrial animal meats and secondary products were not allowed thus for a significant part of the year, the traditional Mediterranean staples of oil, wheat, wine and marine fish were consumed abundantly supplemented with vegetables and legumes, eggs and cheese. However, when allowed, meat was available to all levels of society. Isotope data from northern sites from Spain and other sites around the Mediterranean basin also suggest that the late medieval population had a varied diet which included C_3 and C_4 plants combined with terrestrial and an increase in the marine resources compared to the previous periods (Bertrán Roigé 1990; Bertrán Roigé 1999; Maranges 2006: 45, 55-57, 157-159, 249-250; Thibaut i Comalada 2006: 38-4, 70-71; Bertrán Roigé 2013; Alexander et al. 2015; Fàbrega 2016: 30) (see Chapter B.4.2.3 and Appendix 5.2.3).

Similar to what was observed in the English populations, the late medieval Catalan populations possibly ate more fish and meat than the Roman Catalan one and more fish and possibly slightly less meat than the early medieval populations. If that is true, it then makes sense that the prevalence of DISH for this population lies between the other two periods (LM: 9.0%; R: 6.9%; EM: 12.3%) when all the stages of the disease are taken into account.

It is worth noting that as it wa observed in the previous periods, this difference is again not-significant suggesting that different factors possibly influence the development of the disease and/or that the differences expected based on the documentary and archaeological records were less dramatic than originally thought.

B.6.5 DISH in post medieval populations

Unlike the previous time periods, the number of individuals that could be studied from post-medieval Catalan site of Sant Esteve de Canapost was very limited. Only six individuals could be analysed and the significant male bias (83.3%) of the sample makes it impossible to draw any meaningful demographic profile. Also, as no cases of DISH were identified, it is not possible to evaluate the prevalence of DISH in this population and compare it with others. This population will not be further commented.

The sample size of 27 individuals from the English post-medieval population of Wolverhampton is also very small compared to the previous ones so it is not possible to draw a reliable demographic profile nor meaningful conclusions on the prevalence of DISH. Nevertheless, compared to the previous English populations, if all the stages of the disease are taken into account, the post medieval prevalence of DISH is similar to the Romano-British sample (7.4% and 9.0% respectively) and significantly lower to the observed for the early and the late medieval periods.

The prevalence of advanced DISH in Wolverhampton is the same as the one reported by Rogers et al. (1985) for their post-medieval British population. However the 19th to 20th century Portuguese population shows a significantly higher prevalence of DISH which possibly reflecting a difference in diet (Cunha 1993) (Table 77).

Table 77: Summary table of the prevalence of DISH in post-medieval populations

Reference	Site	n.	DISH (%)[1]
This project	Wolverhampton	27	3.7
Rogers et al. (1985)	Post-med. English	54	3.7
Cunha (1993)	Portugal	51	27.4[2]
Mays (2016)	Spitalfields	137	10.2[3]

[1]Considering stages 3 and 4.[2]Prevalence of definite DISH: 27.4%; prevalence of possible DISH: 19.6% (Cunha 1993). [3]14 (10.2%) individuals showed two or more intervertebral bridges. 36 (26.3%) individuals showed non-ankylosed but ossifying anterior longitudinal ligament and 8 (5.8%) showed one bone bridge (Mays 2016:579)

Diet in the industrial post-medieval Wolverhampton was based on a terrestrial protein and C_3 plant-based and a variable but potentially high input of marine resources (Gordon 2015: 160, 166, 179). The new products coming from the Americas, included C_4 plants (e.g. maize and sugar cane), might have supplemented the post-medieval English diet (Fagan 2006: 188; Serjeantson and Woolgar 2006: 130; Müldner and Richards 2007b; Spencer 2011: 99, 105).

This data suggests that, theoretically, the prevalence of DISH in the post-medieval England should be very similar to that found in the previous late medieval population however it seems that the prevalence was, in fact, lower. This could be related to the small sample size or to possible nutritional deficiencies linked with the industrial character of the mid-19th century

Wolverhampton (see section B.3.2.2.4). Associated with the industrial character of Wolverhampton, the overcrowding lead to the empoverishment of the living conditions, to an increase of endemic infectious diseases and metabolic conditions which ultimately lead to the short life expectancy (Adams et al. 2007: 7-12). Therefore there are two reasons to expect that the overall prevalence of DISH in Wolverhampton would be lower compared to the previous periods. First, the short average life expectancy would have made it less likely for a high number of people to develop the disease and second, despite the historical documentation, it seems that the diet was very poor and less meat-rich and thus possibly did not promote the development of the disease.

B.6.6 An isotope signature for DISH?

Most of the archaeological studies that are either focused on DISH or report on the prevalence of DISH note the relationship between DISH and a rich diet, potentially associated with high status individuals or monastic communities (Waldron 1985; Rogers and Waldron 2001; Jankauskas 2003; Verlaan et al. 2007; Giuffra et al. 2010) therefore the scarcity of isotope analysis on individuals with DISH is notable. Besides the work published here, only Müldner and Richards (2007a), Spencer (2008) and Quintelier et al. (2014) investigated the relationship between DISH and diet using stable isotope analysis.

Despite the expected difference in isotope signature for individuals with and without DISH, the results obtained from the Roman populations studied (Section B.5.11.2, Figure 104), do not suggest any carbon or nitrogen isotope difference between the two groups. There is no isotope differences either between individuals with showing different stages of development. Therefore individuals with DISH from Baldock possibly followed a terrestrial C_3-plants based diet while the individuals from Santa Caterina followed a C_3-plants based diet supplemented with terrestrial and marine protein (section B.5.11.1). Similarly, the male individuals with DISH (n= 4) from Fishergate house showed similar isotopic signature to the males without DISH (n=115). Nevertheless, their individual isotope values suggested a high-protein diet with a significant inclusion of marine resources (Müldner and Richards 2007a).

The analysis of eight monastic and non-monastic communities (total sample size= 46; DISH= 23, non-DISH= 23; male= 40, female= 6) showed a nitrogen enrichment in the individuals with DISH compared to the individuals without DISH but the difference in the average of $\delta^{13}C$ is not statistically significant (Spencer 2008). Interestingly, the results show that this significant nitrogen enrichment of the individuals with DISH only holds true when the entire population is taken into account but disappears when the male and female subsamples are analysed separately. No significant difference between sexes was found in the nitrogen isotope signature in the DISH not in the non-DISH subsamples (Spencer 2008). Spencer (2008) noted that despite the statistically significant difference between DISH and non-DISH individuals, the $\delta^{15}N$ values for individuals with DISH were not consistently higher compared to those obtained for individuals without DISH but that there was a clear visual difference in the $\delta^{15}N$ values between individuals with and without DISH. Despite the small sample size, she concluded that dietary differences between these two groups did, in fact, exist and possibly consisted in a higher intake by the individuals with DISH of animal protein and of foods of a higher trophic level possibly of terrestrial origin (e.g. omnivore protein or freshwater resources) as the carbon values still suggests a terrestrial diet.

Quintelier's et al. (2014) analysis on the relationship between DISH and diet using isotope analysis was based on the remains from the Carmelite friary in Aalst, Belgium. Of the original sample of 238 found inside the church, the cloister alley and the cloister garth, 12 males were diagnosed with DISH. 39 individuals were sampled for isotope analysis (15 males, 14 females and 10 males with DISH). From the individuals with DISH, samples from ribs and the lesions themselves were taken however no differences were found between the two types of sample as most variation fell within the error of mass spectrometry (±0.2‰). Their results show that males with DISH showed slightly higher $\delta^{13}C$ and $\delta^{15}N$ compared to the individuals without DISH however these differences were not statistically significant which they argued was possibly as a result of the small sample size.

Taking into account these three studies and the results obtained in this project, it is not clear that there exists an isotopically different diet between individuals with and without DISH. Furthermore, as Spencer (2008: 254) argued, even when there might be a significant difference in the nitrogen levels, it is possible that it is not related to a different diet but that it reflects physiological processes as variation in this isotope has been found to be relate growth, illness and physiological stress (Katzenberg and Lovell 1999; Waters-Rist and Katzenberg 2010; Beaumont et al. 2015; D'Ortenzio et al. 2015). Assuming that there is a relationship between DISH and social status (a statement that should be re-evaluated taking into account all the stages of DISH) it is also possible that the dietary differences were not reflected on the isotope signature because the types of food consumed by the different social groups were isotopically similar. In fact, through time, it seems that wealth was strongly reflected in the types of meat consumed and the ability to afford a more diverse and exclusive foodstuff (e.g. goat, pig, marine fish depending on the time period and the region) that could have little impact on the overall dietary isotopic signature (e.g. garum, wild game) (Mays 1997; Müldner and Richards 2005; Thibaut i Comalada 2006: 38, 59; Trickett 2006; Müldner and Richards 2007a; Redfern et al. 2010: 46; Fàbrega 2016). Nevertheless, it is interesting that while the shifts in the prevalence of DISH seem to correspond with the changes in consumption of animal protein, this is not the only rich or high caloric foodtype which could be linked to the disease. Some marine species as well as dairy products are also calorie-dense and are known to have been consumed in these regions throughout time. However, beyond environmental archaeological reports and documentary sources, their contribution to the overall diet is very difficult to assess because the isotopic signature of diary products is similar to the terrestrial animal protein and the consumption of high-fat marine resources was possibly reduced and limited to a certain segment of the society. Finally, it is possible that other social rules (e.g. patriarchy, ethnicity, religion and social roles) and the geographical location of the studied population could mask the small differences resulting from a different dietary pattern between groups (Garnsey 1999; Privat et al. 2002; Alexander et al. 2015).

B.6.7 Differential prevalence of DISH in English, Catalan and other ancient populations – insights in the ethiopathogenesis of DISH

It is notable that despite the shifts in the prevalence of DISH from the Roman to the early medieval and finally to the late medieval populations, the English sample tends to show a slightly higher prevalence across periods, and while this difference is not statistically significant, it is maintained even when dietary changes possibly promoted the increase in the prevalence of the disease. Without extensive isotope data, without a good understanding of the diet followed by these populations and even without a proper screening on the prevalence of DISH in modern societies nor a clearer image of the possible genetic background of DISH, it is not possible to theorise on the reasons behind this trend of a 3-4% gap which does not seem to be associated to a difference in populations longevity.

For all periods and for both regions, the reported documentary and archaeological information and data is biased on the *type* of cereal, fish or meat and in the rare cases where vegetables and pulses are referred, usually it is in a list, with little information regarding *how much* these foodtypes contributed towards the overall diet. Modern and, it appears, historical Mediterranean diet was heavily reliant on cereals, oil, wine, pulses and vegetables and supplemented by a variable amount of fish and meat. As this diet is based on the availability of locally grown products resulting from a generally benevolent climate, is it possible that, for this same climatic reason, English populations throughout time have had to rely more heavily on cereals and meat or fish rather than on vegetables and pulses? If this hypothesis were true, then theoretically, English populations should show consistently higher prevalence of DISH, however the data shows no significant difference. This findings probably indicate that diet is not the only factor influencing the appearance of DISH.

A second factor that could explain these somehow unexpected findings is genetic predisposition. Several studies have tried to elucidate whether DISH has a genetic aetiology (e.g. Spagnola et al. 1978; Gorman et al. 2005; Bruges-Armas et al. 2006; Villari et al. 2009). And some clinical results seem to indicate that there is a genetic predisposition to develop the condition that could be population or even family-specific (De la Rúa and Orúe 1992; Koga et al. 1998; Havelka et al. 2001; Gorman et al. 2005; Tsukahara et al. 2005). The difficulty in arguing a genetic predisposition in archaeological human remains is that while there are population-wide studies specifically targeting the prevalence of DISH, they tend to not be directly comparable, and there are extensive geographical areas where data is completely missing. Furthermore, while some researchers have suggested a genetic aetiology to explain the prevalence of DISH in ancient populations (Crubézy 1996; Rogers et al. 1997), to the knowledge of the author, there has been only one attempt at directly investigating this relationship using aDNA analysis (Spencer 2008).

Spencer (2008: 158) aimed at identifying genetic links between individuals with DISH by finding whether the cases of DISH could have belonged to the same biological family taking into account that family groups were often buried in the same monastic or lay cemeteries. From a possible of 74 samples, aDNA sequencing was successful in 31 individuals, 10 of which were individuals with DISH. The findings suggest that DISH is not related to the maternal genealogic line (mtDNA analysis was targeted for the sequencing) however the author concluded that these results did not rule out a genetic factor as the maternal lineage is only one pathways of genetic inheritance (Spencer 2008: 263).

When analysing the prevalence of early (stages 1 and 2) and advanced (stages 3 and 4) DISH, the increase or decrease of prevalence between different time periods is directly linked to the changes in the number of individuals showing early DISH (Figure 88 in Section B.5.5). The constancy in the prevalence of advanced DISH across time periods agrees with the results obtained from the Lithuanian populations of the 1st and the 2nd millennium AD (Jankauskas 2003), from the pre-Columbian Chilean populations (Arriaza 1993) and from the British populations from the Romano-British to the post-medieval period (Rogers et al. 1985) (Table 14 in section B.1.1). Furthermore, Crubézy (1996) also indicated that the prevalence of DISH in two Neolithic necropolis, Vedrovice in Moravia and Nitra in Slovakia, was very similar to that found in the medieval population from southwest France. These studies applied different diagnostic criteria are, theoretically, not directly comparable. However as the diagnostic criteria used by Jankauskas (2003), Arriaza (1993) and Rogers et al. (1985) required at least four vertebrae affected by the ankylosis and Crubézy (1997) applied Arlet and Mazières' (1985) method which required three vertebrae to be affected to issue a definite diagnosis, it is possible to accept that these studies as broadly comparable. It is therefore possible to confirm that prevalence of *advanced* DISH remain remarkably constant across time (before reaching the contemporaneous period) and within each geographical region. Commenting on his results, Crubézy (1996) suggested that this constancy of prevalence, always found to be around 10%, across periods and in between geographical regions supported the genetic aetiology of DISH.

However, while not affecting the validity of Crubézy's (1996) hypothesis, there are three reasons to suggest that this 'genetic factor' might be a 'predisposition' influenced by population idiosyncrasies and external factors. First, while the prevalence remains fairly stable throughout time it does seem to vary between populations from different regions. Archaeological Lithuanian and even Neolithic eastern European populations seem to have a somewhat higher prevalence than pre-Columbian Chilean, Catalan or British populations, which show prevalence values well below the 10% benchmark defined by Crubézy (1996) (Table 14 in Section B.1.1). Secondly, none of these studies have taken into account the early stages of development of DISH which, in this project, have been found to drive the changes in prevalence between time periods. And finally, the research investigating the link between specific gene and DISH has suggested the possibility that genes COL11A2 and COL6A1 could be related to the development of DISH but *only* in the Japanese modern population as no correlation between the expression of these genes and presence of DISH has been found in the Czech population (Tsukahara et al. 2005). So while it is very likely that a variable genetic predisposition to develop DISH exists, it is also likely that external factors (e.g. dietary habits) influence the expression of the disease. This hypothesis would then merge both theories, the existence of a predisposing genetic factor and the widely accepted fact that DISH is directly related to dietary and nutritional factors. The combination of both factors would then result in the variable prevalence of DISH across time periods when all stages, and not only the most advanced ones, are included in the diagnosis of DISH. To investigate this hypothesis, an exhaustive study of the prevalence of all stages of DISH using a single diagnostic criterion needs to be carried out in chronologically and geographically diverse (archaeological and modern) sample with comparable social status and this data combined with a comprehensive dietary study per each population.

B.6.8 Shift of prevalence of DISH from historic to modern populations

Comparing the prevalence of DISH in historical populations to the data obtained from modern populations, it is evident that the prevalence of DISH is significantly higher in modern populations, for all age groups, for both sexes and across the globe (Table 1 in Section A.1.1). It is possible that the impressive sample size these studies could collate (e.g. 12,585 by Julkunen et al. (1971), 20,000 by Tsukamoto et al. (1977)) might have affected the final calculation of the prevalence values. However even when populations where the prevalence of DISH in the different age groups has been reported and had a sample size comparable to the one analysed in here (e.g. Cassim et al. 1990; Kiss et al. 2002b; Diederichs et al. 2011) the prevalence in modern period is still significantly higher than in the past. Citing the osteological paradox, Bombak (2012) suggested that the lower prevalence of DISH in past populations compared to the modern was related to the shorter life span of the first ones. This statement becomes partially challenged when the earlier stages of development of the disease are considered and the presence of DISH can be better assessed. This is because, despite the fact that possibly shorter life might have reduced the number of individuals showing the fully developed condition, assuming that the disease is constantly advancing, the presence of the earlier stages the pathogenesis of DISH would point at the possible prevalence of DISH if the individuals had lived longer. The results reported in here therefore suggest that the lower prevalence of the disease in past is, at least not totally, influenced by their shorter life expectancy.

As the prevalence of DISH is set to increase in the coming decades because of its association to life-style related factors, such as obesity and Type II diabetes (Kiss et al. 2002b; Denko and Malemud 2006) it is very possible that these same factors drove the increase in the prevalence from historic periods to the present. Before exploring further these factors, it is worth noting that even the early medieval populations who showed the highest overall prevalence of DISH and supposedly followed high-protein diet potentially conductive of DISH, still based their diet on cereals (Montanari 1988: cited in Salamon 2008; Banham 2004: 13). Thus not surprisingly, the prevalence of *advanced* DISH remained stable compared to the Roman and the late medieval period.

Moving towards more modern populations, the 19th - 20th century one from Coimbra could be considered the earliest modern population analysed and it already showed a prevalence of definitive DISH of 27.5% and of possible DISH of 19.6% (Cunha 1993). While caution should be exercised when reading these results since the sample size is small (n=51) and the population seems to have been significantly old and of a high socio-economic status, these values suggest that by the end of the 19th century, the prevalence had already escalated from the rates observed in the post-medieval and the late medieval populations. However, Julkunen’s et al. (1971) and Tsukamoto’s et al. (1977) data show significantly lower prevalence of DISH (Table 1, Section A.1.1). These two studies would then contradict the significant increase in the prevalence of DISH suggested by the Portuguese population, possibly indicating that the exponential increase started to happen later in the 20th century. In fact, all the studies published post-90s show a significantly higher prevalence of DISH (Table 1, Section A.1.1). However to understand when this change in trend really happened, exhaustive studies of modern populations for different geographical regions should be carried out.

Interestingly, the prevalence of conditions commonly associated with DISH, like obesity and diabetes, have increased significantly since the 1980s. Worldwide obesity has tripled since 1980 (WHO 2002), from 1993 to 2011, obesity in England increased by at least 10% (males: 13% to 24%; females: 16% to 26%) (NHSIC 2013) and in Spain, between 1997 and 2000, the prevalence of adult obesity increased from 13.6% to 14.5% (Costa-Font and Gil 2005). Linked to this increase in obesity over the last decades, the global prevalence of diabetes type II in the adult population has also increased from 4.7% to 8.5%, this rise being more significant in low- and middle-income countries. In the European region, an estimated 5.3% of the adult population (33 million people) suffered from diabetes in 1980 while by 2014, the prevalence had risen to an estimated 7.3% (64 million people) (WHO 2016). With this context of increased dietary and metabolic imbalances, it is therefore not completely unexpected that the prevalence of DISH has also significantly risen in the past few decades.

B.6.9 Relationship between DISH, age and sex

The general consensus in the clinical environment is that DISH affects primarily men over the age of 50 and the prevalence increase with age (Julkunen et al. 1971; Maat et al. 1995; Mata et al. 1997; Weinfeld et al. 1997; Hannallah et al. 2007). In the cases where the prevalence of DISH has been calculated in archaeological collections, this bias towards the male individuals has also been identified even when different methods have been applied (Arriaza 1993; Maat et al. 1995; Jankauskas 2003; Kacki and Villotte 2006; Oxenham et al. 2006; Kim et al. 2012).

The prevalence of DISH in the samples analysed increased with age. The study of the relationship between DISH and age in both populations show that for most time periods, the older adults (60+ years at the time of death) show the highest prevalence. The only exception to this trend is the late medieval English population where the overall prevalence is similar in the young and old adult groups and lower in the middle adult cohort however the young individuals show predominantly early stages of DISH while the old individuals show more advanced DISH (Table 37 and Figure 86 in Section B.5.4.1). These results are complicated to compare with other published results as the majority of the studies carried out on archaeological human remains have published the prevalence of DISH in the “adult” population or have established a certain age threshold, usually 40+ (Table 14 in Section B.1.1).

Only Kim et al. (2012) reported the prevalence of the disease by age groups. In their study of 96 Korean individuals from the Joseon dynasty (16^{th} – 18^{th} century AD) the prevalence of DISH in males increased from nil for the 20 to 35 the age group (n=5), to 4.5% for the 35 to 50 age group (n=22) and to 13.4% for the 50+ age group (n=21). In their study, no female cases of DISH were found. Two points need to be taken into account at comparing these results to those obtained in here, first, the age groups are not exactly the same (20 – 40, 40 – 60 and 60+ have been used in this project). And second, the diagnostic criteria used by Kim and colleagues (2012) is a modified combination of methods which consider a positive diagnosis of DISH when at least three vertebral bodies were affected. This criteria is broadly equivalent to the stage 4 of development used in this project. Taking these two considerations into account and re-calculating the prevalence of DISH in each age group to include the female individuals, the prevalence of DISH in the old adult Korean individuals is similar to the observed in the contemporaneous English old adult cohort. Both, Korean and English samples show significantly higher prevalence rates of DISH than all Catalan samples analysed (Table 78).

Table 78: Prevalence of DISH in the Korean population compared to prevalence of stage 4 of DISH in the Catalan and English samples (%)

		Young adult	Middle adult	Old adult
Korean sample*	16^{th} – 18^{th} c.	0.0 (0/18)	2.7 (1/37)	9.1(3/33)
Catalan sample	Roman	0.0 (0/23)	0.0 (0/11)	0.0 (0/32)
	Early medieval	0.0 (0/25)	0.0 (0/9)	4.2 (1/24)
	Late medieval	0.0 (0/20)	0.0 (0/12)	0.0 (0/36)
English sample	Roman	0.0 (0/18)	0.0 (0/10)	10.0 (3/30)
	Early medieval	0.0 (0/40)	0.0 (0/16)	0.0 (0/39)
	Late medieval	5.0 (1/20)	0.0 (0/13)	8.7 (2/23)
	Post-medieval	0.0 (0/11)	0.0 (0/4)	13.0 (1/8)

*Based on data published by Kim et al. (2012).

The analysis of the demographics of the stages of DISH gives a further insight in how the disease is presented in the Catalan and the English populations. In general, as it has been pointed out earlier, older individuals tend to show higher prevalence rates however the correlation between old age and advanced stage of DISH is not always straight forward (Figures 83 – 86 in section B.5.4.1). For example, all the early cases of DISH (stages 1 and 2) seen in the Roman Catalan population were found in old adults while in the Romano-British population, all stages of DISH can be found in young and middle adults however stage 4 were only found in old adults. This pattern was also observed in the late medieval populations suggesting a more consistent correlation between old age and advanced stages of the disease in the English population. With this small sample size, it is not possible to investigate the meaning of this trend but it is possible that the Catalan individuals developed the disease at a more advanced age. However this hypothesis would not explain why in the early medieval period, the relationship between advanced DISH and old age seems to be maintained for the Catalan population while despite the increase of the overall prevalence, the majority of the Anglo-Saxon individuals with DISH are old adults showing early stages of the disease.

The results obtained for the English and the Catalan samples confirm a male bias even when the early stages of the disease are introduced in the diagnostic criteria. The higher prevalence of DISH in males is not only maintained across time periods but it is also observed in both geographical regions (Tables 38 and Figure 87 in section B.5.4.2). This pattern is consistent with the majority of the published data from archaeological populations for which separate male/female data was recorded (Table 14 in Section B.1.1) and the majority of the modern populations (Table 1 in Section A.1.1).

B.6.10 Distribution of spinal lesions in archaeological human remains

It is generally agreed that the most commonly affected region is the lower thoracic and the higher lumbar section (e.g. Forestier and Lagier 1971; Tsukamoto et al. 1977; Resnick et al. 1978; Cunha 1993). The results obtained from the Catalan and the English historical populations while agreeing with this “thoracolumbar” distribution, also seem to have the centre of the disease slightly lower than previously reported.

While this suggest that the distribution of DISH is roughly maintained through time, the slightly lower thoracic and slightly greater lumbar involvement observed the archaeological sample could suggesting a more variable distribution of the ankylosis in the studied past samples. However it should be noted that these archaeological examples of advanced DISH could also represent relatively less developed stages of the Bass Collection advanced DISH. Also, it is not possible to know whether the lumbar interlocking lesions would have continued developing to become part of the main ankylosis or would have remained in this pre-bridge stage.

To the knowledge of the author, very little information related to the specific vertebrae affected by the ankylosis in archaeological human remains has been published, nor has the distribution of the disease in the past compared to the modern distribution of the disease been explored. However there are few notable exceptions. 21 of the medieval individuals buried in the Blackfriars Friary (Ipswich, Suffolk) with changes probably associated to DISH, only 15.9% (11/58) of the individuals aged over 40 years old and with at least three vertebrae available for analysis met Rogers's et al. (1987) diagnostic criteria. In this sample, 11 individuals showed ankylosis in the lower thoracic segment (T9-L1) while eight individuals showed mid-thoracic (T4-T9) and 4 showed high-thoracic (C7-T4) involvement. Beyond the thoracic ankylosis, eight individuals showed ossification of the spinal ligaments without ankylosis in the lumbar and two individuals showed these lesions in the cervical spine (Mays 1991: 39-41). The prevalence of DISH at the multi-period site of Wharram Percy, 29 individuals showed lesions suggestive of DISH, however only 3.4% (5/144) individuals of these fulfilled Julkunen's (1971) diagnostic criteria. In this sample, all individuals showed ankylosis in at least the lower half of the thoracic segments, two individuals showed involvement of C5-6 and two individuals of lumbar vertebrae and all individuals showed ligamentous ossification without complete ankylosis in the lumbar segment (Mays et al. 2007: 158-159). Finally Mays (2016) reported that in the post-medieval site of Spitalfields, of the 71 bone bridges observed, 10 were located at the upper thoracic spine (C7-T4), 38 in the mid-thoracic (T4-T9) and 23 in the lower thoracic segment (T9-L1). These studies concur with the results obtained here that the mid- and lower-thoracic spine is the most affected but that lumbar involvement, even if the ossification has not progressed to ankylosis, is a common finding. All these studies also suggest that involvement of the cervical spine is the least observed feature in DISH.

Further analysis with a significantly bigger sample of well-preserved spines are needed to explore these distributions of spinal manifestations of DISH however as the cause behind this specific distribution pattern is still unknown, so far, it is not possible to understand the implications of this shift.

B.6.11 Relationship between DISH and discarthrosis and extra-spinal manifestations

The results obtained from the study of archaeological human remains further confirm the findings discussed in the previous section which indicated that DISH and discarthrosis can and do co-exist in the same individual (Figure 90 in Section B.5.7). While their aetiology is different, discarthrosis is related to the degeneration of the intervertebral disc (Waldron 2009: 43) and DISH is most possibly related to generalised metabolic imbalances (e.g. el Miedany et al. 2000; Kiss et al. 2002b; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Miyazawa and Akiyama 2006), the prevalence of both, discarthrosis and DISH, increase with age (Prescher 1998; Fujiwara et al. 1999; Listi and Manhein 2012) thus their co-morbidity in archaeological populations should be expected (Section A.4.5). It is clear that the Catalan population shows a lower prevalence of this degenerative condition compared to the English one. As their respective demographic profiles are directly comparable (Section B.5.1.5), this difference is unlikely to be related to differential longevity or, indeed, their demographic profile. It is therefore possible that the English population has a higher predisposition to develop this condition.

Regarding the relationship between the spinal and the extra-spinal manifestations of DISH, the results obtained from the archaeological samples mimic, yet again, those obtained from the WM Bass Donated Skeletal Collection (Section A.4.6). Table 60 (section B.5.8.2) summarises the findings regarding the state of the entheses in Catalan and English populations when the entire population or only the individuals with DISH are taken into account. Interestingly, for all populations, the most common state of the *M. triceps brachii* enthesis at the olecranon and of the *M. quadriceps femoris,* at the base of the patella, is smooth or uneven while the entheseal changes found at the insertion of the Achilles tendon tend show slightly bigger entheses usually smaller than 2mm.

The results of the entheseal analysis on the olecranon show that the majority of the population, 48.8% and above, show no changes at this location regardless of the DISH status. However only between 25.0% and 32.2% of the cases show lesions ranging between spicules and 1.9mm lesions at the calcaneal tuberosity, suggesting that enthesopathies at the Achilles tendon vary significantly between individuals. It is worth noting that previous studies had set a threshold of 2 or 3mm to consider the enthesopathy as part of the diagnostic criteria of DISH to be able to differentiate them from those lesions resulting from the combined effect of microtraumatism and age (Crubézy 1989; Crubézy and Crubézy-Ibanez 1993; Vidal 2000; Kacki and Villotte 2006). The majority of the individuals with DISH show right and left enthesophytes measuring less than 2mm at the *M. triceps brachii* and *M. quadriceps femoris* insertion (81.6% and 51.3% of this sub-sample, respectively) (Tables 57 and 58 in Section B.5.8.2). These results follow a similar trend to those obtained when individuals without DISH are considered as 91.4% and 80.7% show either no or smaller than 2mm entheseal changes at the *M. triceps brachii* insertion and *M. quadriceps femoris* insertions, respectively. In contrast, 69.1% of the individuals without DISH show enthesophytes smaller than 2mm at the Achilles tendon insertion and only 38.9% of the individuals with DISH show enthesopathies of less than 2mm at this site (Table 59 in Section B.5.8.2). This suggests not only that individuals with DISH tend to develop bigger enthesopathic lesions but also that this insertion shows the highest inter-individual variability. It is worth noting that this insertion is the only one where enthesophyte size seems to increase with age (Figure 93 in Section B.5.8.3), therefore it is possible that the apparent relationship between spinal lesions and the calcaneal changes is also related to the fact that both lesions are age-influenced. Sadly there is no reference against which these results could be compared the prevalence of the extra-spinal manifestations in the individuals with or without DISH is not recurrently reported (see section A.4.8.2).

The archaeological data indicates that individuals with and without DISH do not differ significantly in the development of the extra-spinal enthesopathies thus further challenging the idea that DISH is defined by spinal *and* extra-spinal manifestations (Sections B.4.6 and B.4.8.2). Furthermore, the analysis of the relationship between the entheseal changes and the stages of development of DISH did not produce conclusive results as none of the entheses studied show any correlation between the severity of the lesions and the advanced stages of DISH. This confirms the results observed in the first part of the thesis that suggested that the development of the extra-spinal manifestations may or may not be related to the presence of the spinal lesions (Table 10 in Section A.3.5.2 for results and Section A.4.6 for discussion).

Finally, regarding the discussion about the symmetry or bilateralism of the extra-spinal manifestations (see section A.4.8.1), the results obtained from the archaeological human remains show that, in all but for one case (marked with an asterisk in Table 60, Section B.5.8.2), the extra-spinal manifestations are symmetrical.

To understand the relationship between these two manifestations, a bigger sample size including individuals with and without DISH with known age at death and other appendicular enthesopathy-inducing factors (such as obesity and activity) should be analysed. With this type of data would allow a better understanding of the relationship between the spinal and the extra-spinal and therefore the definition of a more accurate diagnostic criteria for DISH.

B.6.12 Study of the co-morbidities between DISH and other nutrition and metabolism-related conditions

Beyond analysing the relationship between DISH and diet through stable isotope analysis, a palaeopathological analysis of all the individuals that fulfilled the spinal inclusion criteria was carried out. DISH has been recurrently related to wealthy and high-protein diet in archaeology (De la Rúa and Orúe 1992; Jankauskas 2003; Kacki and Villotte 2006; Giuffra et al. 2010), thus it was originally hypothesised that the prevalence of rich diet indicators (e.g. gout and carious lesions) would be more prevalent in individuals with DISH than in the "healthy" population while indicators of stress or poor diet (e.g. scurvy and osteomalacia) would be a less likely co-morbidity of DISH. A positive correlation between osteoarthritis and DISH was expected as both conditions are age and obesity related (Ortner 2003: 547; Messier 2008; King et al. 2013). Finally, as rickets and enamel hypoplasia reflect vitamin D and metabolic stress during childhood, unless childhood health was a risk factor for DISH, the prevalence of residual rickets and linear enamel hypoplasia in the adult population should be similar in the DISH and non-DISH population (see section B.2.3 for a discussion of each condition).

As expected, the results obtained from the analysis of the historical Catalan and English samples when investigated separately show that in both regions, individuals with and without DISH showed similar levels of healed rickets and linear enamel hypoplasia (see section B.5.9). It is worth noting that some clinical data suggests that early obesity might be related to DISH, however by “early obesity” these studies mean at least in the mid-twenties (Mata et al. 1997, Kiss et al. 2002). By this time, rickets and linear enamel hypoplasia, which develop when the bones are still growing and teeth are developing respectively, would have already become permanent markers. Therefore, the results obtained regarding these two conditions seem reasonable.

The prevalence of scurvy in individuals with DISH is similar to in individuals without DISH. While it was originally expected that the prevalence of scurvy would be lower in individuals with DISH, it is very possible that the vitamin C-rich products (e.g. leafy greens) were widely available therefore the probability of developing scurvy would be equal independently of the DISH status. The English sample show a higher prevalence compared to the Catalan one (10.2% and 2.4%

respectively) and even when the post-medieval sample of Wolverhampton, which showed an overall prevalence of 20%, is removed the prevalence of scurvy in the English sample is 9.1%. Given the characteristics of the Catalan diet, the probability of developing it should have been very low (see section B.4.2 and Appendix 5.2), thus concurring with the results obtained. Finally, while it is not possible to know how available vitamin C-rich products would have been for past English populations, the significantly higher prevalence of scurvy, could suggest that these would have been less available than in Catalonia maybe due to shorter growing seasons or even due to cultural preferences.

The results regarding the prevalence of gout, osteoarthritis and carious lesions are surprising, as it was expected that the individuals with DISH would have shown higher prevalence compared to the individuals without DISH. This was expected because gout is associated to the deposition of urate crystals and it has traditionally been associated to rich diet, which seems to be a risk factor for the development of DISH (Ortner 2003: 583-584). The progression of osteoarthritis in weight-bearing joints has been associated to obesity, which is also common feature in modern patients with DISH (Forestier and Rotes-Querol 1950; Utsinger 1985; Sarzi-Puttini and Atzeni 2004; Denko and Malemud 2006; Messier 2008; Diederichs et al. 2011; King et al. 2013). Finally, sugar and carbohydrate intake, linked to the formation of carious lesions, are associated with the development of diabetes which is one of the several metabolic imbalances potentially associated with DISH (Kiss et al. 2002b; Sarzi-Puttini and Atzeni 2004; Westeveld et al. 2014). There are very few clinical and even fewer, if any, palaeopathological studies that have investigated the prevalence of these co-morbidities. In the archaeological context all the references to the co-morbidity of DISH and gout were found in case study cases. For example Ferdinand I of Medici suffered DISH and gout (Giuffra et al. 2010), and Cosimo I of Medici suffered from DISH and, according to contemporary reports, gout of the knee however palaeopathological analysis disagreed with the historical diagnosis (Villari et al. 2009). Clinically, Littlejohn and Hall (1982) reported that in a study of 99 gout patients, 44% also suffered from DISH however the study had no control sample analysing the prevalence of gout in non-DISH patients. Regarding the statistically significant difference in the prevalence of osteoarthritis between the English and the Catalan population, it is notable that similar results were found when comparing the religious sites of Blackfriars Friary, Gloucestershire, UK (c.1241-1539 AD) and Church of Santa María de Zamartze Navarra, Spain (c. 10-15th centuries AD) (Bohling et al. *in press*). The authors suggested that the statistically significant difference observed in the prevalence of osteoarthritis on the acromioclavicular, wrist and lumbar joints was possibly linked to the combination of genetic, dietary and lifestyle risk factors.

Earlier studies suggested that DISH was asymptomatic and its presence was a state of health without clinical relevance or it was even argued to have a protective effect (Hutton 1989; Schlapbach et al. 1989; Beyeler et al. 1992; Tangrea et al. 1992). However, while these extreme changes are rarely observed in the archaeological populations, some clinical studies suggest that individuals with DISH show a higher percentage of spinal fractures and spinal trauma complications, including death, compared to control groups, as well as dysphagia and apnea associated to the cervical extension of the ankylosis (Hughes et al.

1994; Mata et al. 1997; Papakostas et al. 1999; Epstein 2000; Mader 2002; Matan et al. 2002; Naik et al. 2004; Ebo et al. 2005; Nelson et al. 2006; Hannallah et al. 2007; Westerveld et al. 2009; Vengust et al. 2010; Diederichs et al. 2011) (see section A.1.4). Furthermore, while the link between DISH and diabetes mellitus is not completely clear, it seems that modern patients with DISH are more likely to suffer from metabolic and cardiovascular-related conditions (see section A.1.1). Notably, while none of the individuals from the Bass Collection analysed reported pain, apnea or dysphagia in the donation records, 52.5% of the sample did show at least one nutrition or metabolic-related condition, such as hypercholesterolemia, hyperlipidemia and hypertension, and 35% had some kind of cardiovascular condition (Section A.4.7). These findings therefore suggest that DISH cannot be considered a health status without clinical significance, as Hutton (1989) had hypothesised, as its associated conditions can have fatal consequences and therefore its impact needs to be considered under the view of the osteological paradox.

Despite being identified in modern populations, obesity, diabetes and metabolic syndrome were possibly also present in individuals from past times. Thus is it possible that the individuals with DISH show the same prevalence of gout, carious lesions and osteoarthritis compared to those without DISH because of the conditions that DISH is associated with (i.e. obesity, diabetes and metabolic syndrome)? This means that individuals with DISH had a higher rate of early mortality due to these associated conditions and therefore the rich-diet markers (i.e. gout) did not have time to develop. This is a difficult argument to accept because the populations selected for this project were intentionally chosen to represent the average lay society and not the wealthy or monastic communities. Therefore while undoubtedly some individuals might have developed these high risk conditions (i.e. type 2 diabetes mellitus and metabolic syndrome), the probability of a significant number of individuals developing them as a result of a very rich diet is rather low. Furthermore, if the premise that the high young mortality in individuals with DISH were true, the data should have shown a higher prevalence of DISH in young and middle adults individuals. Instead, in both regions the prevalence of DISH is significantly higher in older individuals. Finally, gout and OA are not caused by DISH, but should, at least theoretically, be related through shared aetiological factors. Thus there is no reason to expect that these two conditions would have developed *a posteriori* resulting in individuals with DISH but without rich-diet markers.

The reality is that, because the aetiology and the genetic factors linked to DISH still remain largely unknown, it is very complicated to elucidate the co-morbidity of DISH with other conditions. Theoretically, DISH should be related with high-protein markers and, clinically, individuals with DISH have been found to have increased uric acid (Kiss et al. 2002b; Miyazawa and Akiyama 2006), however the relationship between these blood markers and the actual development of the palaeopathologically identifiable gouty lesions is unclear. It is very likely that until the triggers and influencing factors of DISH are not well characterised, from the palaeopathological point of view, we will not be able to understand the correlation (or lack thereof) between DISH and other nutrition-related factors. While this research falls mostly within the realm of clinical analysis, from an archaeological point of view, the poly-morbidity of DISH should be further investigated using bigger samples with reliable and comparable age estimation and sex assessment and well-established social backgrounds.

B.7 CONCLUSIONS PART B

This project aimed to investigate the prevalence of DISH through time in England and Catalonia and to explore the relationship between DISH and diet as characterised by a combination of isotope and archaeological data as well as documentary sources. DISH was diagnosed using the diagnostic criteria defined in Part A which identified four stages of development: isolated outgrowths (Stage 1), touching or interlocking outgrowths (Stage 2), presence of one complete intervertebral bridge (Stage 3), presence of an ankylosis involving more than two vertebrae (Stage 4). The analysis of the relationship between DISH and age and sex is in agreement with the general clinical and archaeological consensus, whereby older individuals show the highest prevalence rates and male show consistently higher prevalence that females even when all the stages of development are taken into account. Furthermore, while young and middle adult individuals usually show the early stages of the disease, all stages of DISH can be found in the old adult cohort. This pattern would argue for a variable age of onset which would depend on individual characteristics.

If diet is a significant factor in the development of DISH, from the dietary analysis of past English and Catalan populations it was hypothesised that the prevalence would change across periods. The diachronic analysis of DISH showed that while the hypothesis was correct, results are not statistically significant. Nonetheless, the prevalence trends of the disease in England and Catalonia are very similar: the Roman samples show the lowest prevalence rates while the early medieval samples show the highest rates observed. The prevalence decreases in the late medieval samples and, in post-medieval England, the prevalence of DISH decreases even further.

Stable isotope analysis data from the Romano-British site of Baldock and the Roman Catalan site of Santa Caterina suggest that these populations followed a slightly different diet. The Romano-British individuals consumed mainly terrestrial resources and the Catalan individuals consuming a combination terrestrial and marine resources. Archaeological data and documentary resources however suggest that Roman Catalan was a pre-eminently vegetarian society; a dietary pattern that would agree with the low prevalence of DISH observed in this population. It is not possible to ascertain how meat-dependent Romano-British society was, however it is possible that their intake of meat was greater than in the Catalan one due to their military background. This diet would probably have led to a higher prevalence of DISH. However, in this sample, while the Romano-British shows a marginally higher prevalence of DISH, specially when only advanced DISH is considered, there does not seem a significant difference in the prevalence of DISH between the Roman samples analysed.

When considering all the stages of DISH, the overall prevalence found in the early medieval English and Catalan samples was, as expected, higher than all contemporary populations with available data. However the prevalence rates of advanced DISH are comparable to other contemporaneous sites (e.g. St. Peter’s Church in Barton-on-Humber, UK). It seems that both early medieval populations were more reliant on meat than the previous Roman populations; a shift that, if true, would help to explain the significant increase in the prevalence of DISH between the two periods.

Compared to contemporary populations, the prevalence of advanced DISH in the late medieval English and Catalan samples is similar to that observed in other English medieval populations. The late medieval English and Catalan diet was heavily influenced by the religious imposition of fasting days whereby meat and animal derived products were not allowed for almost half of the year. As a result, both populations saw a significant increase in the consumption of fish. It is worth noting that, corresponding with this dietary shift, both populations show a prevalence of DISH which is intermediate between the Roman (which seem to have had a low consumption of meat and fish) and the early medieval population (which seem to have been highly dependent on meat).

The diachronic analysis of the trends in the prevalence of DISH suggest that shifts in dietary habits could have influenced the development of the disease. However the absence of significant differences in prevalence of DISH in populations that theoretically should have shown it (e.g. Roman vs early medieval) possibly suggests that factors other than dietary differences influence the development of DISH. It is then possible that the theoretical differences in the diet of individuals living in nucleated settlements were, in reality, not significantly different and/or that the development of the disease also depends on other factors like genetic predisposition.

It was hypothesised that if individuals with DISH followed a richer diet (i.e. higher consumption of meat and fatty fish), they would also show higher carbon and nitrogen isotopic values. However the isotope values obtained from the individuals with DISH are very similar to those obtained for the “healthy” population suggesting that the individuals with DISH might have followed an isotopically similar diet than the rest of the population. While in-depth analysis should be undertaken to investigate the association between DISH and social status, assuming the existence of such a relationship, it is still possible that while diet might have been different between social groups, wealth might have reflected in the exclusivity and variety of foodstuff which possibly had a small impact on the overall isotopic signature. It is nevertheless worth noting that the development of DISH is, most probably, multifactorial and that individual genetic differences might have influenced the development of the condition given the individual's dietary habits.

Regarding the study of the relationship between DISH and discarthrosis, the results obtained from the archaeological samples corroborate the findings from the Bass Collection suggesting that both conditions can, and do, co-exist in the same individual. Interestingly, the English population shows higher prevalence of discarthrosis compared to the Catalan one; a difference possibly related to a differential predisposition to develop this condition.

DISH has been described as having spinal and extra-spinal manifestations; however the results obtained from the archaeological sample concurs with the findings from the Bass Collection indicating that the link between these two manifestations is far from clear. Individuals with and without DISH show similar pattern of enthesopathic changes at the insertion of the *M. triceps brachii,* the *M. quadriceps femoris* and the Achilles tendon. The enthesophytes at the insertion of the Achilles tendon in the calcaneus are the only ones that could be related to the spinal manifestations of DISH, however their stronger association to age possibly indicate that their development could also be related to age and therefore that the association between the spinal manifestations and the calcaneal enthesophytes is circumstantial and multifactorial more rather than causal.

The prevalence of scurvy, healed rickets and linear enamel hypoplasia is similar in the individuals with and without DISH in both regions. Interestingly, English populations show slightly higher prevalence of scurvy compared to the Catalan populations, possibly indicating that vitamin C-rich foods (e.g. leafy greens) were less available to the English population. The prevalence of gout, osteoarthritis and carious lesions is similar in the individuals with and without DISH. While these results were unexpected, the aetiology of DISH remains largely unknown thus it is not possible infer which other conditions it might be associated. Furthermore, while theoretically DISH, gout and carious lesions are associated to rich diet they could have different specific triggers. This study also found a higher prevalence of osteoarthritis in the English sample compared to the Catalan one regardless of the DISH status which is possibly associated to genetic and lifestyle factors.

The results obtained from the analysis of archaeological samples from England and Catalonia corroborate that DISH is very likely associated to diet but suggest that the expression of the disease is possibly linked to a genetic predisposition. Furthermore, these results confirm those obtained from the Bass Collection suggesting that DISH and discarthrosis co-exists in the same individual. And further highlights the need to investigate the relationship between the spinal and the extra-spinal manifestations taking into account the effect of age in the development of the extra-spinal enthesopathies. Finally, no specific relationship was found between DISH and any of the conditions associated with a rich diet (i.e. gout, osteoarthritis and carious lesions) or the deficiency-associates conditions (i.e. scurvy, healed rickets, linear enamel hypoplasia).

3. CONCLUSIONS

This project aimed at improving our understanding of DISH by adopting a munti-disciplinary approach. The first part of the project, the analysis the individuals with DISH from the WM Bass Donated Skeletal Collection was aimed at understanding the progression of the condition, the relationship between the spinal and the extra-spinal manifestations and the co-ocurrence of DISH and discarthrosis as well as the co-morbidity with other nutrition-related and metabolic conditions. The study of the archaeological human remains from England in Catalonia in the second part was aimed at investigating how the changes in diet through time might have influenced the presence of this condition from the Roman to the post-medieval period.

The analysis corroborated that the spinal manifestations of DISH are characterised by an antero-lateral ankylosis at the lower thoracic section of the spine which develops cranio-caudally. At either end of the ankylosis, the earlier stages of the disease (i.e. isolated and touching or interlocking outgrowths) can be found; possibly indicating the direction of the ossification. In keeping with the consensus, the main ankylosis was found to be located at the right half of the spine, however its location shifted from central to the vertebral body in the first four thoracic vertebrae, to become true right and later split into two sheaths located at the lateral thirds of the lower thoracic and lumbar vertebrae. This distribution is possibly associated with the route of the descending aorta. The left side of the vertebral body can also show DISH-like enthesopathies however these tend to be less voluminous than the right ones.

The results obtained in Part A and B suggest that the DISH and discarthrosis can be found in the same individual. However it seems that the vertebrae with DISH lesions have less tendency to develop discarthrosis. These results could suggests that the bone bridges associated with DISH have a protective effect on the vertebral endplate by decreasing the pressure on the intervertebral disc and thus reducing the probability of developing degenerative changes. However vertebrae without DISH can develop age-related degenerative changes in the vertebral endplates and discarthrosis.

The data obtained from modern as well as archaeological human remains also agreed in questioning the relationship between the spinal and the extra-spinal manifestations usually associated with DISH. While these results seem to contradict the general consensus, it is worth noting that there is a considerable lack of data obtained from controlled samples in the clinical literature and, to the knowledge of the author, this is the first time that the association between these two enthesopathic manifestations has been explored using archaeological human remains. Further age-controlled and sex and pathology matched studies need to be carried out to further understand the relationship between the spinal and the extra-spinal manifestations of DISH.

The analysis of the relationship between DISH and age and sex in the archaeological Catalan and English samples is in agreement with the general consensus, whereby older individuals show the highest prevalence rates and male individuals show consistently higher prevalence that female individuals. Interestingly, as young and middle adult individuals usually show the early stages of the disease but all stages of DISH can be found in the old adult cohort, it is possible to suggest that the age of onset of DISH depends on individual characteristics.

Regarding the co-morbidity of DISH with other conditions it was hypothesised that the individuals with DISH would show higher prevalence of nutrition-related and metabolic conditions. It was shown in Part A, that more than half of the individuals analysed from the Bass Collection showed at least one type of metabolic derangement and a high prevalence of cardiovascular conditions was also observed. However in the archaeological sample the prevalence of metabolic excess or conditions associated with rich-diet (e.g. carious lesions and gout) was similar in all individuals regardless of their DISH status. No association between DISH and deficiency-related conditions (e.g. scurvy, healed rickets) was found. While these results might seem contradictory, they possibly reflect our lack of understanding of the aetiology and pathogenesis of DISH.

And finally, the diachronic analysis of the prevalence of DISH in England and Catalonia revealed shifts in the prevalence of DISH between periods that could be partially explained by temporal changes in the dietary patterns of each region. The non-statistically different prevalence rates of DISH in the English sample compared to the Catalan sample in all periods combined with the consistency in the prevalence of advanced DISH possibly suggest that beyond diet, the prevalence of DISH is also influenced by other factors, possibly a genetic predisposition to the condition. However to really understand the factors that influence the expression of DISH in different societies, from an archaeological point of views, further analysis combining cultural studies, dietary analysis (combining isotope and archaeological data and documentary resources) and DNA analysis should be undertaken.

4. FUTURE WORK

This project aimed at increasing our understanding of DISH in several levels, from the characterisation of its manifestations to how changing dietary patterns and lifestyles might have influenced the prevalence of DISH through time and across geographical regions. However, it has been recurrently noted in both discussions (sections A.4 and B.7) that problems usually surrounding sample size and representation have limited the extent of interpretation derived from the results. This section will give some ideas on how the future work regarding the investigation of DISH itself and its prevalence in past societies could be focused. It is important to note that to improve our understanding of DISH, clinical and osteoarchaeological research should be combined however, in this section, the emphasis will be set only on osteoarchaeological approaches.

Future work regarding Part A: Identification of the early stages of DISH:

- The sample size of known-age individuals with DISH needs to be increased to elucidate whether males and females show different pattern of ankylosis.
- The internal structure of the DISH-related outgrowths should be further explored using 3D/CT scans. Ideally osteophytes should also be analysed using the same technique to allow a comparative analysis.
- To investigate further the relationship between the spinal and the extra-spinal manifestations of DISH, a sample including age and sex-matched individuals with and without DISH should be analysed.

- The relationship between DISH, age and ossification of the costal cartilage should be explored using a sample of known-age and –sex individuals.
- Analysis on modern collections with complete and accurate medical records (including childhood health) for all the individuals needs to be carried out to investigate how DISH related to adult-onset and long-standing metabolic imbalances and cardiopathies.

Future work regarding Part B: DISH in the archaeological context:

- Despite the difference in prevalence of DISH between English and Catalan samples, it prevalence in other regions should be investigated to corroborate the trends observed in this thesis. The prevalence of DISH in post-medieval populations should be investigated with a significantly bigger sample size.
- This project only included lay populations from nucleated settlements. To have a better understanding on the prevalence of DISH through time, the type of sites analysed should be expanded to include rural, religious and high status communities.
- A bigger sample of known-age individuals with DISH is needed to corroborate the findings regarding the variability in the age of onset of DISH and to investigate whether this is influenced by sex.
- The relationship between the spinal and the extra-spinal manifestations of DISH in past populations needs to be further examined with a bigger sample of age and sex-matched individuals with and without DISH to investigate whether the relationship between these two manifestations has changed through time. This sample would also be suitable to explore how sex and

activity might have influenced the development of the extra-spinal enthesopathy.

- The possible isotope signature for DISH should be further examined taking into account regional diets and possible social status of the individuals. Furthermore, the possibility that different diets could give similar isotopic signatures should be further explored using collections where the social status can be inferred from the archaeological context and where faunal remains (to be isotopically analysed to create an animal baseline) and documentary sources are available.
- The co-morbidity of DISH with other nutrition-related and metabolic conditions should be further explored with a larger sample of individuals with DISH. Furthermore, it would be interesting to investigate whether obesity can be reliably identified in archaeological human remains and then explore the relationship of obesity and DISH from an archaeological point of view.
- Stable isotope analysis on human and faunal remains from Catalonia should be carried out to complement the scarce archaeological data and documentary resources and obtain a better idea of how the diet changed through time.

5. REFERENCES

A.d.B. (2018) *Carta arqueològica de Barcelona: Muralles romanes de Barcino.* Barcelona: *http://cartaarqueologica.bcn.cat/736* Accessed 17/05/2018.

Adams, J., Colls, K. and St Peter's Collegiate, C. (2007) *Out of darkness, cometh light: life and death in nineteenth-century Wolverhampton : excavation of the overflow burial ground of St Peter's Collegiate Church, Wolverhampton 2001-2002.* Vol. 442:3 Oxford: Archaeopress.

Aeberli, D., Schett, G., Esera, P., Seitz, M. and Villiger, P. M. (2011) Serum Dkk-1 levels of DISH patients are not different from healthy controls. *Joint Bone Spine* Letters to the Editor (78), 422-423.

Aguelo i Mas, J., Huertas Arroyo, J. and Puig i Verdaguer, F. (2005) Santa Caterina de Barcelona: Assaig d'ocupació i evolució. *Quaderns d'arqueologia i història de la ciutat de Barcelona* (1), 13-43.

Aguelo Mas, J., Huertas Arroyo, J. and Puig, F. (2001) Excavacions a l'antic Convent de Santa Caterina de Barcelona (Barcelonès) *Tribuna Arqueològica* (11), 208-224.

Albarella, U. (2006) Pig husbandry and pork consumption in medieval England. In Woolgar, C. M., Serjeantson, D., and Waldron, T. (editors) *Food in Medieval England: Diet and Nutrition.* New York: Oxford University Press. 71-87.

Alcock, J. P. (2001) *Food in Roman Britain.* Stroud: Tempus.

Alexander, M. M., Gerrard, C. M., Gutiérrez, A. and Millard, A. R. (2015) Diet, society, and economy in late medieval Spain: Stable isotope evidence from Muslims and Christians from Gandía, Valencia. *American Journal of Physical Anthropology* 156 (2), 263-273.

Alonso Martinez, N. (2005) Agriculture and food from the Roman to the Islamic Period in the North-East of the Iberian peninsula: archaeobotanical studies in the city of Lleida (Catalonia, Spain). *Vegetation History and Archaeobotany* 14 (4), 341-361.

Alonso Martínez, N. (2000) Registro arqueobotánico de Cataluña occidental durante el II y I milenio a.n.e. *Complutum; Vol 11 (2000)*.

Alves Cardoso, F. and Henderson, C. Y. (2010) Enthesopathy formation in the humerus: Data from known age-at-death and known occupation skeletal collections. *American Journal of Physical Anthropology* 141 (4), 550-60.

Ambrose, S. H. (1991) Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* 18 (3), 293-317.

Ambrose, S. H. (1993) Isotopic analysis of paleodiets: Methodological and interpretative considerations. In Sandford, M. K. (editor) *Investigations of ancient human tissue: chemical analyses in anthropology.* Philadelphia: Gordon and Breach. 59-130.

Arlet, J. and Mazières, B. (1985) The hyperostotic disease. *Revue de Médecine Interne* 6(5):553–64.

Arriaza, B. T. (1993) Seronegative spondyloarthropathies and diffuse idiopathic skeletal hyperostosis in ancient northern Chile. *American Journal of Physical Anthropology* 91 (3), 263-78.

Arriaza, B. T., Merbs, C. F. and Rothschild, B. M. (1993) Diffuse idiopathic skeletal hyperostosis in Meroitic Nubians from Semna South, Sudan. *American Journal of Physical Anthropology* 92 (3), 243-8.

Aufderheide, A. C., Rodríguez Martín, C. and Langsjoen, O. (2011) *The Cambridge encyclopedia of human paleopathology.* Cambridge: Cambridge University Press.

Balasse, M., Mainland, I. and Richards, M. P. (2009) Stable isotope evidence for seasonal consumption of marine seaweed by modern and archaeological sheep in the Orkney archipelago (Scotland). *Environmental Archaeology* 14 (1), 1-14.

Banham, D. (2004) *Food and drink in Anglo-Saxon England.* Stroud: Tempus.

Barrett, J. H., Locker, A. M. and Roberts, C. M. (2004) 'Dark Age Economics' revisited: the English fish bone evidence AD 600-1600. *Antiquity* 78 (301), 618-636.

Beaumont, J., Geber, J., Powers, N., Wilson, A., Lee-Thorp, J. and Montgomery, J. (2013) Victims and survivors: Stable isotopes used to identify migrants from the Great Irish Famine to 19th century London. *American Journal of Physical Anthropology* 150 (1), 87-98.

Beaumont, J., Montgomery, J., Buckberry, J. and Jay, M. (2015) Infant mortality and isotopic complexity: New approaches to stress, maternal health, and weaning. *American Journal of Physical Anthropology* 157 (3), 441-457.

Belanger, T. A. and Rowe, D. E. (2001) Diffuse idiopathic skeletal hyperostosis: musculoskeletal manifestations. *Journal of the American Academy of Orthopedic Surgery* 9 (4), 258-67.

Bell, M. (1977) *Excavations at Bishopstone.* Vol. 115. Sussex Archaeological Society.

Benjamin, D. J., Berger, J. O., Johannesson, M., Nosek, B. A., Wagenmakers, E. J., Berk, R., Bollen, K. A., Brembs, B., Brown, L., Camerer, C., Cesarini, D., Chambers, C. D., Clyde, M., Cook, T. D., De Boeck, P., Dienes, Z., Dreber, A., Easwaran, K., Efferson, C., Fehr, E., Fidler, F., Field, A. P., Forster, M., George, E. I., Gonzalez, R., Goodman, S., Green, E., Green, D. P., Greenwald, A. G., Hadfield, J. D., Hedges, L. V., Held, L., Hua Ho, T., Hoijtink, H., Hruschka, D. J., Imai, K., Imbens, G., Ioannidis, J. P. A., Jeon, M., Jones, J. H., Kirchler, M., Laibson, D., List, J., Little, R., Lupia, A., Machery, E., Maxwell, S. E., McCarthy, M., Moore, D. A., Morgan, S. L., Munafó, M., Nakagawa, S., Nyhan, B., Parker, T. H., Pericchi, L., Perugini, M., Rouder, J., Rousseau, J., Savalei, V., Schönbrodt, F. D., Sellke, T., Sinclair, B., Tingley, D., Van Zandt, T., Vazire, S., Watts, D. J., Winship, C., Wolpert, R. L., Xie, Y., Young, C., Zinman, J. and Johnson, V. E. (2018) Redefine statistical significance. *Nature Human Behaviour* 2 (1), 6-10.

Bertrán Roigé, P. (1990) L'Alimentació a l'Edat Mitjana. *Dovella* 33, 33-37.

Bertrán Roigé, P. (1999) L'alimentació dels pobres, hostes i servidors al palau pontifici d'Avinyó (1375). *Acta historica et archaeologica mediaevalia* 20'21, 369-380.

Bertrán Roigé, P. (2013) La alimentación de pobres y peregrinos en la Cataluña medieval. In García Guatas, M., Piedrafita Pérez, E., and Barbacil, J. (editors) *La alimentación en la Corona de Aragón (siglos XIV-XV): actas del Simposio organizado por la Academia aragonesa de gastronomía en el sexto centenario del Compromiso de Caspe, Zaragoza (23 y 24 de marzo de 2012)* Zaragoza: 43-64.

Beyeler, C., Schlapbach, P., Gerber, N. J., Fahrer, H., Hasler, F., van der Linden, S. M., Burgi, U., Fuchs, W. A. and Ehrengruber, H. (1992) Diffuse idiopathic skeletal hyperostosis (DISH) of the elbow: a cause of elbow pain? A controlled study. *British Journal of Rheumatology* 31 (5), 319-23.

Beyeler, C., Schlapbach, P., Gerber, N. J., Sturzenegger, J., Fahrer, H., van der Linden, S., Burgi, U., Fuchs, W. A. and Ehrengruber, H. (1990) Diffuse idiopathic skeletal hyperostosis (DISH) of the shoulder: a cause of shoulder pain? *British Journal of Rheumatology* 29 (5), 349-53.

Bocherens, H. and Drucker, D. (2003) Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology* 13 (1-2), 46-53.

Boddington, A. (1996) *Raunds furnells: the Anglo-Saxon church and churchyard.* London: English Heritage.

Bogaard, A., Heaton, T. H. E., Poulton, P. and Merbach, I. (2007) The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34 (3), 335-343.

Bohling, S., Buckberry, J., Valle de Tarazaga, F. and Bonthorne, E. (*in press*) An osteological analysis of degenerative joint disease in two medieval European populations. *Trends in Biological Anthropology*.

Bol, R., Eriksen, J., Smith, P., Garnett, M. H., Coleman, K. and Christensen, B. T. (2005) The natural abundance of ^{13}C, ^{15}N, ^{34}S and ^{14}C in archived (1923–2000) plant and soil samples from the Askov long-term experiments on animal manure and mineral fertilizer. *Rapid Communications in Mass Spectrometry* 19 (22), 3216-3226.

Boldsen, J., Milner, G., Konigsberg, L. and Wood, J. (2002) Transition analysis: a new method for estimating age from skeletons In Hoppa, R. and Vaupel, J. (editors) *Paleodemography.* Cambridge: Cambridge University Press. 73-106.

Bombak, A. E. (2012) Diffuse Idiopathic Skeletal Hyperostosis and the Osteological Paradox. *Totem: The University of Western Ontario Journal of Anthropology* 20 (1).

Bourbou, C. and Richards, M. P. (2007) The Middle Byzantine menu: palaeodietary information from isotopic analysis of humans and fauna from Kastella, Crete. *International Journal of Osteoarchaeology* 17 (1), 63-72.

Brickley, M. and Ives, R. (2008) *The bioarchaeology of metabolic bone disease.* Oxford: Academic Press.

Brickley, M., Mays, S. and Ives, R. (2005) Skeletal manifestations of vitamin D deficiency osteomalacia in documented historical collections. *International Journal of Osteoarchaeology* 15 (6), 389-403.

Brigode, M., Francois, R. J. and Dory, M. A. (1982) Radiological study of the sacroiliac joints in vertebral ankylosing hyperostosis. *Annals of Rheumatic Diseases* 41 (3), 225-31.

Brothwell, D. R. (1981) *Digging up bones: the excavation, treatment and study of human skeletal remains.* 3rd edition. Oxford: Oxford University Press/British Museum (National History).

Brown, T. A., Nelson, D. E., Vogel, J. S. and Southon, J. R. (2006) Improved collagen extraction by modified Longin method. *Radiocarbon 30(2):171-177 (1988)*.

Bruges-Armas, J., Couto, A. R., Timms, A., Santos, M. R., Bettencourt, B. F., Peixoto, M. J., Colquhoun, K., McNally, E. G., Carneiro, V., Herrero-Beaumont, G. and Brown, M. A. (2006) Ectopic calcification among families in the Azores: clinical and radiologic manifestations in families with diffuse idiopathic skeletal hyperostosis and chondrocalcinosis. *Arthritis and Rheumatology* 54 (4), 1340-9.

Bullock, M., Márquez, L., Hernández, P. and Ruíz, F. (2013) Paleodemographic age-at-death distributions of two Mexican skeletal collections: A comparison of transition analysis and traditional aging methods. *American Journal of Physical Anthropology* 152 (1), 67-78.

Burleigh, G. R., Fitzpatrick-Matthews, K. J., Allen, D., North Hertfordshire Archaeological, S. and North Hertfordshire District Council Museums, S. (2010) *Excavations at Baldock, Hertfordshire, 1978-94: Volume 1, An Iron Age and Romano-British cemetery at Wallington Road.* Vol. 1. Letchworth?: North Hertfordshire District Council Museums Service and North Hertfordshire Archaeological Society.

Byers, S. N. (2011) *Introduction to forensic anthropology.* 4th Int. edition. London: Pearson.

Calisaneller, T., Ozdemir, O., Tosun, E. and Altinors, N. (2005) Dysphagia due to diffuse idiopathic skeletal hyperostosis. *Acta Neurochirurgica* 147 (11), 1203-1206.

Cameron, A. and Roberts, C. (Unpublished report) Gambier Parry Lodge, Gloucester: Human skeletal report. held at Biological Anthropology Research Centre, University of Bradford.

Canci, A., Marchi, D., Caramella, D., Fornaciari, G. and Borgognini Tarli, S. M. (2005) Coexistence of melorheostosis and DISH in a female skeleton from Magna Graecia (Sixth Century BC). *American Journal of Physical Anthropology* 126 (3), 305-10.

Carey, B. M., Parkin, G. J. S., Cunliffe, W. J. and Pritlove, J. (1988) Skeletal toxicity with isotretinoin therapy: a clinico-radiological evaluation. *British Journal of Dermatology* 119 (5), 609-614.

Cassim, B., Mody, G. M. and Rubin, D. L. (1990) The prevalence of diffuse idiopathic skeletal hyperostosis in African blacks. *British Journal of Rheumatology* 29 (2), 131-2.

Castells Navarro, L. (2013) *DISH everywhere? A palaeodemographic study of diffuse idiopathic skeletal hyperostosis in the Romano-British and the medieval populations*. MSc. Bradford, UK: University of Bradford.

Chanchairujira, K., Chung, C. B., Kim, J. Y., Papakonstantinou, O., Lee, M. H., Clopton, P. and Resnick, D. (2004) Intervertebral disk calcification of the spine in an elderly population: radiographic prevalence, location, and distribution and correlation with spinal degeneration. *Radiology* 230 (2), 499-503.

Chenery, C., Eckardt, H. and Müldner, G. (2011) Cosmopolitan Catterick? Isotopic evidence for population mobility on Rome's Northern frontier. *Journal of Archaeological Science* 38 (7), 1525-1536.

Chenery, C., Müldner, G., Evans, J., Eckardt, H. and Lewis, M. (2010) Strontium and stable isotope evidence for diet and mobility in Roman Gloucester, UK. *Journal of Archaeological Science* 37 (1), 150-163.

Cheung, C., Schroeder, H. and Hedges, R. E. M. (2012) Diet, social differentiation and cultural change in Roman Britain: new isotopic evidence from Gloucestershire. *Archaeological and Anthropological Sciences* 4 (1), 61-73.

Ciurana Prast, J. (2011) *Pràctiques i rituals funeraris a Tàrraco i el seu ager (segles II AC - III/IV DC)*. PhD Thesis. Tarragona: Universitat Rovira i Virgili.

Colominas, L. (2017) Roman conquest and changes in animal husbandry in the North-East of the Iberian Peninsula: Searching for patterns, rates and singularities. *Archaeofauna* 26, 9-22.

Contreras Mas, A. (2017) *La cuina en temps de Ramón Llull.* Documenta Balear S.L.

Cool, H. E. M. (2006) *Eating and drinking in Roman Britain.* Cambridge: Cambridge University Press.

Costa-Font, J. and Gil, J. (2005) Obesity and the incidence of chronic diseases in Spain: A seemingly unrelated probit approach. *Economics & Human Biology* 3 (2), 188-214.

Crabtree, P. J. (2010) Agricultural innovation and socio-economic change in early medieval Europe: evidence from Britain and France. *World Archaeology* 42 (1), 122-136.

Craig, O. E., Biazzo, M., O'Connell, T. C., Garnsey, P., Martinez-Labarga, C., Lelli, R., Salvadei, L., Tartaglia, G., Nava, A., Reno, L., Fiammenghi, A., Rickards, O. and Bondioli, L. (2009) Stable isotopic evidence for diet at the Imperial Roman coastal site of

Velia (1st and 2nd centuries AD) in Southern Italy. *American Journal of Physical Anthropology* 139 (4), 572-83.

Crubézy, E. (1996) Etiopathogenesis of skeletal hyperostosis. A study of a European population that lived 7700 years ago. *Revue du Rhumatisme Engl Ed* 63 (7-8), 481-4.

Crubézy, E. and Trinkaus, E. (1992) Shanidar 1: a case of hyperostotic disease (DISH) in the middle Paleolithic. *American Journal of Physical Anthropology* 89 (4), 411-20.

Crubézy, E. (1989) Diffuse idiopathic skeletal hyperostosis: Diagnosis and importance in paleopathology. *Journal of Paleopathology* 3 (2), 107-118.

Crubézy, E. and Crubézy-Ibanez, E. (1993) Evaluation of diagnostic criteria for hyperostotic diseases on a series of skeletons. Epidemiological implications. *Revue du Rhumatisme (Ed. francaise: 1993)* 60 (9), 586-590.

Crubézy, E. and Trinkaus, E. (1992) Shanidar 1: a case of hyperostotic disease (DISH) in the middle Paleolithic. *American Journal of Physical Anthropology* 89 (4), 411-20.

Cunha, E. (1993) Évolution de la maladie hyperostosique à Coimbra de l'époque médiévale à la fin du XIXe siècle. *Bulletins et Mémoires de la Société d'anthropologie de Paris*, 313-320.

Cybulski, J. S. (1988) Skeletons in the Walls of Old Quévec. *Northeast Historical Archaeology* 17 (1): 61-84.

D'Ortenzio, L., Brickley, M., Schwarcz, H. and Prowse, T. (2015) You are not what you eat during physiological stress: Isotopic evaluation of human hair. *American Journal of Physical Anthropology* 157 (3), 374-388.

Daoussis, D. and Andonopoulos, A. P. (2011) The emerging role of Dickkopf-1 in bone biology: is it the main switch controlling bone and joint remodeling? *Seminars in Arthritis and Rheumatology* 41 (2), 170-7.

Daragon, A., Mejjad, O., Czernichow, P., Louvel, J. P., Vittecoq, O., Durr, A. and Le Loet, X. (1995) Vertebral hyperostosis and diabetes mellitus: a case-control study. *Annals of Rheumatic Diseases* 54 (5), 375-8.

Davies, R. W. (1971) The Roman Military Diet. *Britannia* 2, 122-142.

De la Rúa, C. and Orúe, J. (1992) Health conditions in a monastic community of the Basque Country (16th and 17th century). *Journal of Palaeopathology* 4, 193-200.

Denko, C. W. and Malemud, C. J. (2006) Body mass index and blood glucose: correlations with serum insulin, growth hormone, and insulin-like growth factor-1 levels in patients with diffuse idiopathic skeletal hyperostosis (DISH). *Rheumatology International* 26 (4), 292-7.

Diederichs, G., Engelken, F., Marshall, L. M., Peters, K., Black, D. M., Issever, A. S., Barrett-Connor, E., Orwoll, E., Hamm, B. and Link, T. M. (2011) Diffuse idiopathic skeletal hyperostosis (DISH): relation to vertebral fractures and bone density. *Osteoporosis International* 22 (6), 1789-97.

Dobney, K., Hall, A. and Kenward, H. (1999) It's all garbage... A review of bioarchaeology in the four English *colonia* towns. In Hurst, H. (editor) *The coloniae of Roman Britain: New studies and a review. Papers of the conference held at Gloucester on 5-6 July, 1997.* Portsmouth, Rhode Island: Journal of Roman Archaeology, Supplementary Series Number 36. 15-35.

Dobney, K., Jacques, D., Barrett, J. and Johnstone, C. (2007) *Farmers, monks and aristocrats: the environmental archaeology of an Anglo-Saxon estate at Flixborough, North Lincolnshire, UK.* Vol. 3. Oxford: Oxbow.

Dufour, E., Bocherens, H. and Mariotti, A. (1999) Palaeodietary Implications of Isotopic Variability in Eurasian Lacustrine Fish. *Journal of Archaeological Science* 26 (6), 617-627.

Dyer, C. (1988) Changes in Diet in the Late Middle Ages: The Case of Harvest Workers. *The Agricultural History Review* 36 (1), 21-37.

Ebo, D. G., Uytterhaegen, P. J., Lagae, P. L., Vander Mijnsbrugge, A. M. and Goffin, J. (2005) Choking, sore throat with referred otalgia and dysphagia in a patient with diffuse idiopathic skeletal hyperostosis (DISH). *Acta Clinica Belgica* 60 (2), 98-101.

Eckertova, M., Krskova, K., Penesova, A., Radikova, Z., Zlnay, D., Rovensky, J. and Zorad, S. (2009) Impaired insulin secretion and uptake in patients with diffuse idiopathic skeletal hyperostosis. *Endocrine Regulations* 43 (4), 149-55.

Ejstrud, B. (2006) Size matters: estimating trade of wine, oil and fish-sauce from amphorae in the first century AD. In Bekker-Nielsen, T. and Curtis, R. I. (editors) *Ancient Fishing and Fish Processing in the Black Sea Region.* Aarhus University Press. 171-182.

el Miedany, Y. M., Wassif, G. and el Baddini, M. (2000) Diffuse idiopathic skeletal hyperostosis (DISH): is it of vascular aetiology? *Clinical and Experimental Rheumatology* 18 (2), 193-200.

Ellis, C. N., Pennes, D. R., Martel, W. and Voorhees, J. J. (1985) Radiographic bone surveys after isotretinoin therapy for cystic acne. *Acta Dermato-venereologica* 65 (1), 83-85.

Epstein, N. E. (2000) Simultaneous cervical diffuse idiopathic skeletal hyperostosis and ossification of the posterior longitudinal ligament resulting in dysphagia or myelopathy in two geriatric North Americans. *Surgical Neurology* 53 (5), 427-31; discussion 431.

Estévez, J. (1987) Dynamique des faunes préhistorique au N-E de la péninsule ibérique. *Archaeozoologia* 1.2, 197-218.

Eviatar, E. and Harell, M. (1987) Diffuse idiopathic skeletal hyperostosis with dysphagia. *The Journal of Laryngology & Otology* 101 (06), 627-632.

Faas, P. (2006) *Around the Roman table: Food and feasting in Ancient Rome.* Chicago: University of Chicago Press.

FAC (2017) *Age, sex and ancestry distribution of the WM Bass Donated Skeletal Collection.* Knoxville, TN: University of Tennessee, Knoxville. http://fac.utk.edu/age-sex-and-ancestry-distribution/ Accessed 05/02/2018.

Fàbrega, J. (2016) *La cuina medieval i renaixentista. Moros, jueus i cristians.* Viena Edicions

Fagan, B. M. (2006) *Fish on Friday: feasting, fasting and the discovery of the New World.* New York;London: BasicBooks.

Fahrer, H., Koch, P., Ballmer, P., Enzler, P. and Gerber, N. (1988) Ectopic ossification following total hip arthroplasty: is diffuse idiopathic skeletal hyperostosis a risk factor? *British Journal of Rheumatology* 27 (3), 187-90.

Forestier, J. and Lagier, R. (1971) Ankylosing hyperostosis of the spine. *Clinical Orthopaedics and Related Research* 74, 65-83.

Forestier, J. and Rotes-Querol, J. (1950) Senile ankylosing hyperostosis of the spine. *Annals of Rheumatic Diseases* 9 (4), 321-30.

Fornasier, V. L., Littlejohn, G., Urowitz, M. B., Keystone, E. C. and Smythe, H. A. (1983) Spinal entheseal new bone formation: the early changes of spinal diffuse idiopathic skeletal hyperostosis. *The Journal of rheumatology* 10 (6), 939-947.

François, R. J., Eulderink, F. and Bywaters, E. G. (1995) Commented glossary for rheumatic spinal diseases, based on pathology. *Annals of the Rheumatic Diseases* 54 (8), 615-625.

Freemont, A. J. (2002) Enthesopathies. *Current Diagnostic Pathology* 8 (1), 1-10.

Frigola Triola, J. (2008) Sant Esteve de Canapost (Forallac, Baix Empordà). Memòria.

Frigola Triola, J. and Punseti Puig, D. (2012) La necròpolis de Sant Esteve de Canapost (Forallac, Baix Empordà). In Molist, N. and Ripoll, G. (editors) *Arqueologia funerària al nord-est peninsular (segles VI-XII).* Barcelona: Monografies d'Olèrdola, MAC. 359-371.

Fujiwara, A., Tamai, K., Yamato, M., An, H. S., Yoshida, H., Saotome, K. and Kurihashi, A. (1999) The relationship between facet joint osteoarthritis and disc degeneration of the lumbar spine: an MRI study. *European Spine Journal* 8 (5), 396-401.

Fuller, B. T., De Cupere, B., Marinova, E., Van Neer, W., Waelkens, M. and Richards, M. P. (2012) Isotopic reconstruction of human diet and animal husbandry practices during the Classical-Hellenistic, imperial, and Byzantine periods at Sagalassos, Turkey. *American Journal of Physical Anthropology* 149 (2), 157-171.

Fuller, B. T., Fuller, J. L., Sage, N. E., Harris, D. A., O'Connell, T. C. and Hedges, R. E. M. (2004) Nitrogen balance and δ15N: why you're not what you eat during pregnancy. *Rapid Communications in Mass Spectrometry* 18 (23), 2889-2896.

Fuller, B. T., Molleson, T. I., Harris, D. A., Gilmour, L. T. and Hedges, R. E. (2006) Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology* 129 (1), 45-54.

Fuller, B. T., Márquez-Grant, N. and Richards, M. P. (2010) Investigation of diachronic dietary patterns on the islands of Ibiza and formentera, Spain: Evidence from carbon and nitrogen stable isotope ratio analysis. *American Journal of Physical Anthropology* 143 (4), 512-522.

Garcia, E., Subirà, M. E. and Richards, M. P. (2004) Régime et société d'après l'analyse des isotopes stables: l'exemple de la population de "Can Reinés" (Mallorca, Espagne, 600 ap. J.C.). *Antropologia* 7, 171-176.

García Llinares, M. G., Moro García, A. and Tuset Bertran, F. (2003) De conjunt paleocristià i catedralici a conjunt parroquial. Transformacions i canvis d'ús de les esglésies de Sant Pere de Terrassa. Segles IV al XVIII. *Terme* 18, 29-58.

García-Collado, M. I. (2016) Food consumption patterns and social inequality in an early medieval rural community in the centre of the Iberian Peninsula. In Quirós Castillo, J. A. (editor) *Social complexity in Early Medieval rural communities. The northwestern Iberia archaeological record.* Oxford: Archaeopress Archaeology. 50-78.

Garnsey, P. (1999) *Food and society in classical antiquity.* New York; Cambridge, U.K: Cambridge University Press.

Garrod, A. P. (1984) Gambier Parry Lodge Estate, Tewkesbury Road, near Kingsholm, Gloucester (SO 836 198). *Glevensis* 18.

Garvie-Lok, S. (2001) *Loaves and fishes: A stable isotope reconstruction of diet in Medieval Greece*. Unpublished PhD dissertation. Alberta: University of Calgary

Geber, J. and Murphy, E. (2012) Scurvy in the Great Irish Famine: evidence of vitamin C deficiency from a mid-19th century skeletal population. *American Journal of Physical Anthropology* 148 (4), 512-24.

Genera i Monells, M., Orri Terrado, E. and Nadal Lorenzo, J. (2010) Datos para una aproximación a las prácticas culinárias de la antigua ciudad de Dertosa: el solar de la Costa dels Capellans núm. 5, Tortosa (Baix Ebre). *Saguntum Extra* 9, 257-262.

Gerber, L. H., Helfgott, R. K., Gross, E. G., Hicks, J. E., Ellenberg, S. S. and Peck, G. L. (1984) Vertebral abnormalities associated with synthetic retinoid use. *Journal of the American Academy of Dermatology* 10 (5, Part 1), 817-823.

Giuffra, V., Giusiani, S., Fornaciari, A., Villari, N., Vitiello, A. and Fornaciari, G. (2010) Diffuse idiopathic skeletal hyperostosis in the Medici, Grand Dukes of Florence (XVI century). *European Spine Journal* 19 Suppl 2, S103-7.

Gordon, R. L. (2015) *Feeding the city: zooarchaeological perspectives on urban provisioning and consumption behaviours in post-medieval England (AD1500 - AD1900)*. PhD. Leicester: University of Leicester.

Gorman, C., Jawad, A. S. M. and Chikanza, I. (2005) A family with diffuse idiopathic skeletal hyperostosis. *Annals of the Rheumatic Diseases* 64 (12), 1794-1795.

Griffin, R., Pitts, M., Smith, R. and Brook, A. (2011) Inequality in the Late Roman Baldock, UK The Impact of Social Factors on Health and Diet. *Journal of Anthropological Research* 67 (4), 533-556.

Guo, Q., Ni, B., Yang, J., Zhu, Z. and Yang, J. (2011) Simultaneous ossification of the posterior longitudinal ligament and ossification of the ligamentum flavum causing upper thoracic myelopathy in DISH: case report and literature review. *European Spine Journal* 20 (2), 195-201.

Gómez i Pallarès, J. (1996) Apunts sobre l'alimentació al mon romà. *Cota Zero* (12), 98-104.

Hagen, A. (1999) *A second handbook of Anglo-Saxon food and drink: production & distribution.* Norfolk: Anglo-Saxon books.

Hagen, A. (2006) *Anglo-Saxon food and drink: production, processing, distribution and consumption.* Norfolk: Anglo-Saxon Books.

Haller, J., Resnick, D., Miller, C. W., Schils, J. P., Kerr, R., Bielecki, D., Sartoris, D. J. and Gundry, C. R. (1989) Diffuse idiopathic skeletal hyperostosis: diagnostic significance of radiographic abnormalities of the pelvis. *Radiology* 172 (3), 835-839.

Han, T. S. and Lean, M. E. J. (2016) A clinical perspective of obesity, metabolic syndrome and cardiovascular disease. *JRSM Cardiovascular Disease* 5: 2048004016633371.

Hannallah, D., White, A. P., Goldberg, G. and Albert, T. J. (2007) Diffuse Idiopathic Skeletal Hyperostosis. *Operative Techniques in Orthopaedics* 17 (3), 174-177.

Harris, J., Carter, A. R., Glick, E. N. and Storey, G. O. (1974) *Ankylosing hyperostosis*. Annals of the Rheumatic Diseases 33(3): 210-215.

Hart, J. and Holbrook, N. (2011) A Medieval Monastic Cemetery within the Precinct of Malmesbury Abbey: Excavations at the Old Cinema Site, Market Cross. *Wiltshire Archaeological Natural History Magazine* 104, 166-192.

Havelka, S., VeselÁ, M., PavelkovÁ, A., RuzickovÁ, Š., Koga, H., Maeda, S., Inoue, I. and Halman, L. (2001) Are DISH and OPLL genetically related? *Annals of the Rheumatic Diseases* 60 (9), 902-903.

Haydock, H., Clarke, L., Craig-Atkins, E., Howcroft, R. and Buckberry, J. (2013) Weaning at Anglo-Saxon Raunds: Implications for changing breastfeeding practice in Britain over two millennia. *American Journal of Physical Anthropolology* 151 (4), 604-12.

Hedges, R. E. M. and Reynard, L. M. (2007) Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34 (8), 1240-1251.

Hendrix, R. W., Melany, M., Miller, F. and Rogers, L. F. (1994) Fracture of the spine in patients with ankylosis due to diffuse skeletal hyperostosis: clinical and imaging findings. *American Journal of Roentgenology* 162 (4), 899-904.

Henning, J. (2009) Revolution or relapse? Technology, agriculture and Early Medieval Archaeology in Germanic Central Europe. In Ausenda, G., Delogu, P., and Wickham, C. (editors) *The Langobards before the Frankish Conquest.* Woodbridge: The Boydell Press. 149-173.

Henrard, J. C. and Bennett, P. H. (1973) [Epidemiological study of vertebral hyperostosis. Survey in an adult population of American Indians]. *Revue du Rhumatisme et des Maladies Osteoarticulaires* 40 (10), 581-91.

Hodges, R. (1982) *Dark age economics : the origins of towns and trade : A.D. 600-1000.* London: Duckworth.

Hoffmann, R. C. (2005) A brief history of aquatic resource use in medieval Europe. *Helgoland Marine Research* 59.

Holton, K. F., Denard, P. J., Yoo, J. U., Kado, D. M., Barrett-Connor, E. and Marshall, L. M. (2011) Diffuse idiopathic skeletal hyperostosis and its relation to back pain among older men: the MrOS Study. *Seminars in Arthritis and Rheumatology* 41 (2), 131-8.

Huelsemann, F., Koehler, K., Braun, H., Schaenzer, W. and Flenker, U. (2013) Human dietary δ15N intake: Representative data for principle food items. *American Journal of Physical Anthropology* 152 (1), 58-66.

Hughes, T. A., Wiles, C. M., Lawrie, B. W. and Smith, A. P. (1994) Case report: dysphagia and sleep apnoea associated with cervical osteophytes due to diffuse idiopathic skeletal hyperostosis (DISH). *Journal of Neurology, Neurosurgery, and Psychiatry* 57 (3), 384.

Hurst, H. R. (1985) *Kingsholm.* Gloucester: Gloucester Archaeological Publications.

Hurst, H. R. (1999) Topography and identity in *Glevum colonia*. In Hurst, H. R. (editor) *The coloniae of Roman Britain: new strudies and a review.* Portsmouth, Rhode Island: Journal of Roman Archaeology.

Hurst, H. R. and Crummy, P. (1999) *The coloniae of Roman Britain: new studies and a review : papers of the conference held at Gloucester on 5-6 July, 1997.* Vol. no. 36. Portsmouth, R.I: Journal of Roman Archaeology.

Hutton, C. (1989) DISH ... a state not a disease? *British Journal of Rheumatology* 28 (4), 277-8.

Iborra Eres, M. P., Mata Parreño, C., Moreno Martín, A., Pérez Jordà, G., Quixal Santos, D. and Vives-Ferrándiz Sánchez, J. (2010) Prácticas culinarias y alimentación en asentamientos ibéricos valencianos. *Saguntum Extra* 9.

Işcan, M. Y. and Loth, S. R. (1985) Age Estimation from the Rib by Phase Analysis: White Females. *Journal of Forensic Sciences* 30 (3).

Işcan, M. Y., Loth, S. R. and Wright, R. K. (1984) Age Estimation from the Rib by Phase Analysis: White Males *Journal of Forensic Sciences* 29 (4).

Ives, R. and Brickley, M. (2014) New findings in the identification of adult vitamin D deficiency osteomalacia: Results from a large-scale study. *International Journal of Paleopathology* 7, 45-56.

Iwasawa, T., Iwasaki, K., Sawada, T., Okada, A., Ueyama, K., Motomura, S., Harata, S., Inoue, I., Toh, S. and Furukawa, K. I. (2006) Pathophysiological Role of Endothelin in Ectopic Ossification of Human Spinal Ligaments Induced by Mechanical Stress. *Calcified Tissue International* 79 (6), 422-430.

Jankauskas, R. (2003) The incidence of diffuse idiopathic skeletal hyperostosis and social status correlations in Lithuanian skeletal materials. *International Journal of Osteoarchaeology* 13 (5), 289-293.

Jim, S., Ambrose, S. H. and R.P., E. (2004) Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: Implications for their use in palaeodietary reconstruction. *Geochimica et Cosmochimica Acta* 68 (1), 61-72.

Jordana Comin, X. (2007) *Caracterització i evolució d'una comunitat medieval catalana. Estudi bioantropològic de les inhumacions de les Esglésies de Sant Pere*. PhD. Barcelona: Universitat Autònoma de Barcelona.

Julkunen, H., Heinonen, O. P. and Pyörälä, K. (1971) Hyperostosis of the spine in an adult population. Its relation to hyperglycaemia and obesity. *Annals of the Rheumatic Diseases* 30 (6), 605-612.

Kacki, S. and Villotte, S. (2006) Maladie hyperostosique et mode de vie: Intérêt d'une démarche bio-archéologique: Exemple du cimentière du Convent des Soeurs Grises de Beauvais (Oise), XV-XVIIIème siècles. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 18 (1-2), 55-64.

Kanstrup, M., Thomsen, I. K., Andersen, A. J., Bogaard, A. and Christensen, B. T. (2011) Abundance of 13C and 15N in emmer, spelt and naked barley grown on differently manured soils: towards a method for identifying past manuring practice. *Rapid Communications in Mass Spectrometry* 25 (19), 2879-87.

Katzenberg, M. A. and Lovell, N. C. (1999) Stable isotope variation in pathological bone. *International Journal of Osteoarchaeology* 9, 316-324.

Katzenberg, M. A. and Saunders, S. R. (editors) (2008) *Biological Anthropology of the Human Skeleton.* Liss (Alan) Inc.

Keenleyside, A., Schwarcz, H., Stirling, L. and Ben Lazreg, N. (2009) Stable isotopic evidence for diet in a Roman and Late Roman population from Leptiminus, Tunisia. *Journal of Archaeological Science* 36 (1), 51-63.

Kenyon, D. W., M. (2006) An Anglo-Saxon Enclosure at Copsehill Road, Lower Slaughter: excavations in 1999. *Transactions Bristol Gloucestershire Archaeological Society* 124, 73-109.

Kilcoyne, R. F., Cope, R. A. Y., Cunningham, W., Nardella, F. A., Denman, S., Franz, T. J. and Hanifin, J. O. N. (1986) Minimal Spinal Hyperostosis with Low-Dose Isotretinoin Therapy. *Investigative Radiology* 21 (1): 41-44.

Kim, M. J., Lee, I. S., Kim, Y. S., Oh, C. S., Park, J. B., Shin, M. H. and Shin, D. H. (2012) Diffuse idiopathic skeletal hyperostosis cases found in Joseon Dynasty Human Sample Collection of Korea. *International Journal of Osteoarchaeology* 22 (2), 235-244.

King, A. (1999) Diet in the Roman world: a regional inter-site comparison of the mammal bones. *Journal of Roman Archaeology* 12 (1), 168-202.

King, A. (2001) Romanization of diet in the western empire: comparative archaeozoological studies. In Keay, S. and Terrenato, N. (editors) *Italy and the West, comparative studies in Romanization.* Oxford: Oxbow Books. 210-223.

King, L. K., March, L. and Anandacoomarasamy, A. (2013) Obesity & osteoarthritis. *The Indian Journal of Medical Research* 138 (2), 185-193.

Kiss, C., O'Neill, T. W., Mituszova, M., Szilágyi, M., Donáth, J. and Poór, G. (2002a) Prevalence of diffuse idiopathic skeletal hyperostosis in Budapest, Hungary. *Rheumatology* 41 (11), 1335-1336.

Kiss, C., Szilagyi, M., Mituszova, M. and Poor, G. (1997) [Prevalence and risk factors in diffuse idiopathic skeletal hyperostosis in a population sample in Hungary]. *Orvosi Hetilap* 138 (25), 1619-23.

Kiss, C., Szilágyi, M., Paksy, A. and Poór, G. (2002b) Risk factors for diffuse idiopathic skeletal hyperostosis: a case–control study. *Rheumatology* 41 (1), 27-30.

Klales, A. R., Ousley, S. D. and Vollner, J. M. (2012) A revised method of sexing the human innominate using Phenice's nonmetric traits and statistical methods. *American Journal of Physical Anthropology* 149 (1), 104-114.

Knaggs, R. L. (1925) Spondylitis deformans. *British Journal of Surgery* 12 (47), 524-546.

Koga, H., Sakou, T., Taketomi, E., Hayashi, K., Numasawa, T., Harata, S., Yone, K., Matsunaga, S., Otterud, B., Inoue, I. and Leppert, M. (1998) Genetic mapping of ossification of the posterior longitudinal ligament of the spine. *American Journal of Human Genetics* 62 (6), 1460-1467.

Kosaka, T., Imakiire, A., Mizuno, F. and Yamamoto, K. (2000) Activation of nuclear factor kappaB at the onset of ossification of the spinal ligaments. *Journal of Orthopaedic Sciences* 5 (6), 572-8.

Kramar, C., Lagier, R. and Baud, C. A. (1990) Thoracic Spinal Hyperostosis in an Early Mediaeval Skeleton. *Scandinavian Journal of Rheumatology* 19 (2), 163-166.

Krogman, W. M. and İşcan, M. Y. (1986) *The human skeleton in forensic medicine.* Second edition. Springfiel, Illinois 62717: Charles C. Thomas.

Krueger, H. W. and Sullivan, C. H. (1984) Models for Carbon Isotope Fractionation Between Diet and Bone. *Stable Isotopes in Nutrition.* American Chemical Society Symposium Series 258: 205-220. *http://dx.doi.org/10.1021/bk-1984-0258.ch014* Accessed 2017/07/25.

Kulikowski, M. (2005) Cities and government in Late Antique Hispania. In Bowles, K. and Kulikowski, M. (editors) *Hispania in Late Antiquity: Current Perspectives.* Leiden, Netherlands: Brill.

Kuperus, J. S., de Gendt, E. E. A., Oner, F. C., de Jong, P. A., Buckens, S. C. F. M., van der Merwe, A. E., Maat, G. J. R., Regan, E. A., Resnick, D. L., Mader, R. and Verlaan, J.-J. (2017) Classification criteria for diffuse idiopathic skeletal hyperostosis: a lack of consensus. *Rheumatology* 56 (7), 1123-1134.

Lagier, R. (1989) Spinal hyperostosis in comparative pathology. *Skeletal Radiology* 18 (2), 99-107.

Leibushor, N., Slonimsky, E., Aharoni, D., Lidar, M. and Eshed, I. (2017) CT Abnormalities in the Sacroiliac Joints of Patients With Diffuse Idiopathic Skeletal Hyperostosis. *American Journal of Roentgenology* 208 (4), 834-837.

Lightfoot, E., Šlaus, M. and O'Connell, T. C. (2012) Changing cultures, changing cuisines: Cultural transitions and dietary change in iron age, roman, and early medieval croatia. *American Journal of Physical Anthropology* 148 (4), 543-556.

Ling, T. C., Parkin, G., Islam, J., Seukeran, D. C. and Cunliffe, W. J. (2001) What is the cumulative effect of long-term, low-dose isotretinoin on the development of DISH? *British Journal of Dermatology* 144: 630-2.

Listi, G. A. and Manhein, M. H. (2012) The Use of Vertebral Osteoarthritis and Osteophytosis in Age Estimation*. *Journal of Forensic Sciences* 57 (6), 1537-1540.

Littlejohn, G. O. and Hall, S. (1982) Diffuse idiopathic skeletal hyperostosis and new bone formation in male gouty subjects. A radiologic study. *Rheumatology International* 2 (2), 83-6.

Littlejohn, G. O. and Smythe, H. A. (1981) Marked hyperinsulinemia after glucose challenge in patients with diffuse idiopathic skeletal hyperostosis. *Journal of Rheumatology* 8 (6), 965-8.

Locker, A. (2007) In piscibus diversis; the bone evidence for fish consumption in Roman Britain. *Britannia* 38, 141-180.

Loveluck, C. P. (1998) A high-status Anglo-Saxon settlement at Flixborough, Lincolnshire. *Antiquity* 72 (275), 146-161.

Lubritto, C., Sirignano, C., Ricci, P., Passariello, I. and Quirós Castillo, A. (2013) Radiocarbon chronology and paleodiet studies on the medieval rural site of Zaballa (Spain): preliminary insights into the social archaeology of the site. *Radiocarbon* 55: 1222-1232.

López-Costas, O. and Müldner, G. (2016) Fringes of the empire: Diet and cultural change at the Roman to post-Roman transition in NW Iberia. *American Journal of Physical Anthropology* 161 (1), 141-154.

Maat, G. J. R. (2004) Scurvy in adults and youngsters: the Dutch experience. A review of the history and pathology of a disregarded disease. *International Journal of Osteoarchaeology* 14 (2), 77-81.

Maat, G. J. R., Mastwijk, R. W. and van der Velde, E. A. (1995) Skeletal distribution of degenerative changes in vertebral osteophytosis, vertebral osteoarthritis and DISH. *International Journal of Osteoarchaeology* 5 (3), 289-298.

MacKinnon, A. (2015) *Dietary reconstruction of Medieval and Early Modern Spanish populations using stable isotopes of carbon and nitrogen*. Masters of Arts. Chico: California State University.

Mader, R. (2002) Clinical manifestations of diffuse idiopathic skeletal hyperostosis of the cervical spine. *Seminars in Arthritis and Rheumatology* 32 (2), 130-5.

Mader, R. (2008) Diffuse idiopathic skeletal hyperostosis: time for a change. *Journal of Rheumatology.* Canada. 35: 377-9.

Mader, R., Buskila, D., Verlaan, J.-J., Atzeni, F., Olivieri, I., Pappone, N., Di Girolamo, C. and Sarzi-Puttini, P. (2012) Developing new classification criteria for diffuse idiopathic skeletal hyperostosis: back to square one. *Rheumatology* 52(2): 326-330.

Mader, R., Dubenski, N. and lavi, I. (2005) Morbidity and mortality of hospitalized patients with diffuse idiopathic skeletal hyperostosis. *Rheumatology International* 26 (2), 132-136.

Mader, R. and Lavi, I. (2009) Diabetes mellitus and hypertension as risk factors for early diffuse idiopathic skeletal hyperostosis (DISH). *Osteoarthritis Cartilage* 17 (6), 825-8.

Mader, R., Novofastovski, I., Rosner, E., Adawi, M., Herer, P. and Buskila, D. (2010) Nonarticular tenderness and functional status in patients with diffuse idiopathic skeletal hyperostosis. *Journal of Rheumatology* 37 (9), 1911-6.

Mader, R., Sarzi-Puttini, P., Atzeni, F., Olivieri, I., Pappone, N., Verlaan, J. J. and Buskila, D. (2009) Extraspinal manifestations of diffuse idiopathic skeletal hyperostosis. *Rheumatology (Oxford)* 48 (12), 1478-81.

Mader, R., Verlaan, J.-J. and Buskila, D. (2013) Diffuse idiopathic skeletal hyperostosis: clinical features and pathogenic mechanisms. *Nature Reviews Rheumatology* 9 (12), 741-750.

Mader, R., Verlaan, J.-J., Eshed, I., Jacome, B.-A., Puttini, P. S., Atzeni, F., Buskila, D., Reinshtein, E., Novofastovski, I., Fawaz, A., Kurt, d. V. and Baraliakos, X. (2017) Diffuse idiopathic skeletal hyperostosis (DISH): where we are now and where to go next. *RMD Open* 3 (1).

Maltby, M. (1997) Domestic fowl on Romano-British sites: Inter-site comparisons of abundance. *International Journal of Osteoarchaeology* 7, 402-414.

Maranges, I. (2006) *La cuina catalana medieval, un festí per als sentits.* Col·lecció Bofarull, núm. 9.

Marks, B., Schober, E. and Swoboda, H. (1998) Diffuse idiopathic skeletal hyperostosis causing obstructing laryngeal edema. *European Archives of Otorhinolaryngology* 255 (5), 256-8.

Martínez Diez, A. and Martínez Flórez, J. (2013) Patología ósea en los restos esqueléticos procedented de la excavación arqueológica de Santa María la Vieja (Navarrete, La Rioja). In *Vetera corpora morbo afflicta: Actas del XI Congreso Nacional de Paleopatología.* Barcelona. Universitat de Barcelona. 443-458.

Mata, S., Chhem, R. K., Fortin, P. R., Joseph, L. and Esdaile, J. M. (1998) Comprehensive radiographic evaluation of diffuse idiopathicskeletal hyperostosis: Development and interrater reliability of a scoring system. *Seminars in Arthritis and Rheumatism* 28 (2), 88-96.

Mata, S., Fortin, P. R., Fitzcharles, M. A., Starr, M. R., Joseph, L., Watts, C. S., Gore, B., Rosenberg, E., Chhem, R. K. and Esdaile, J. M. (1997) A controlled study of diffuse idiopathic skeletal hyperostosis. Clinical features and functional status. *Medicine (Baltimore)* 76 (2), 104-17.

Matan, A. J., Hsu, J. and Fredrickson, B. A. (2002) Management of respiratory compromise caused by cervical osteophytes: a case report and review of the literature. *Spine Journal* 2 (6), 456-9.

Mays, S. (1991) *The Medieval burials from the Blackfriars Friary, School Street, Ipswich, Suffolk (excavated 1983-1985).*

Mays, S. (2002) The Relationship between molar wear and age in an early 19th century AD archaeological human skeletal series of documented age at death. *Journal of Archaeological Science* 29 (8), 861-871.

Mays, S. (2006) The osteology of monasticism in medieval England. In Gowland, R. and Knüsel, C. (editors) *Social archaeology of funerary remains.* Oxford: Oxbow Books.

Mays, S. (2016) Bone-formers and bone-losers in an archaeological population. *American Journal of Physical Anthropology* 159 (4), 577-584.

Mays, S. and Beavan, N. (2012) An investigation of diet in early Anglo-Saxon England using carbon and nitrogen stable isotope analysis of human bone collagen. *Journal of Archaeological Science* 39 (4), 867-874.

Mays, S., Brickley, M. and Ives, R. (2006) Skeletal manifestations of rickets in infants and young children in a historic population from England. *American Journal of Physical Anthropology* 129 (3), 362-74.

Mays, S. and Cox, M. (2000) Sex determination in skeletal remains. In Cox, M. and Mays, S. (editors) *Human osteology in archaeology and forensic science.* London: Greenwich Medical Media. 117-130.

Mays, S., De la Rúa, C. and Molleson, T. (1995) Molar crown height as a means of evaluating existing dental wear scales for estimating age at death in human skeletal remains. *Journal of Archaeological Science* 22 (5), 659-670.

Mays, S. A. (1997) Carbon Stable Isotope Ratios in Mediaeval and Later Human Skeletons From Northern England. *Journal of Archaeological Science* 24 (6), 561-568.

Mays, S. A., Harding, C. and Heighway, C. M. (2007) *The churchyard*. York, University of York.

Maziéres, B. (2013) Diffuse idiopathic skeletal hyperostosis (Forestier-Rotes-Querol disease): what's new? *Joint Bone Spine* 80 (5), 466-70.

McCormick, M., Büntgen, U., Cane, M. A., Cook, E. R., Harper, K., Huybers, P., Litt, T., Manning, S. W., Mayewski, P. A., More, A. F. M., Nicolussi, K. and Tegel, W. (2012) Climate Change during and after the Roman Empire: Reconstructing the Past from

Scientific and Historical Evidence. *The Journal of Interdisciplinary History* 43 (2), 169-220.

McWhirr, A. (1981) *Roman Gloucestershire.* Gloucester: A. Sutton.

Messier, S. P. (2008) Obesity and osteoarthritis: disease genesis and nonpharmacologic weight management. *Rheumatic diseases clinics of North America* 34 (3), 713-729.

Meyer, M. and Forster, E. (1938) Considerations pathogeniques sur "l'hyperostose moniliforme du flanc droit de la colonne dorsale. *Revue du Rhumatisme* 5, 286-293.

Miles A.E.W (1963) The dentitiion in the assessment of individual age in skeletal material. In D.R Brothwell (editor) *Dental anthropology,* 5:191-209

Mintz, S. W. (1985) *Sweetness and power: the place of sugar in modern history.* New York, London: Sifton.

Miyazawa, N. and Akiyama, I. (2006) Diffuse idiopathic skeletal hyperostosis associated with risk factors for stroke: a case-control study. *Spine (Phila Pa 1976)* 31 (8), E225-9; discussion E230.

Molist i Capella, N. and Bosch i Casadevall, J. M. (2012) El cemenetiri medieval de Sant Miquel d'Olèrdola (Olèrdola, Alt Penedès). In Molist, N. and Ripoll, G. (editors) *Arqueologia funerària al nord'est peninsular (segles VI-XII).* Barcelona: Monografies d'Olèrdola 3.2, MAC. 469-494.

Montalbán Martínez, C. (2009) *Memòria del jaciment de Carretera de Castelló nº 34-36. Vila-sacra, Alt Empordà.*

Montanari, M. (1988) *Alimentazione e cultura nel Medioevo.* Rome: Laterza.

Morales Muñiz, D. C. (1992) Pig husbandry in Visigoth Iberia: Fact and theory. *Archaeofauna* 1, 147-155.

Moreland, J. (2000) Ethnicity, power and the English. In Frazer, W. O. and Tyrrell, A. (editors) *Social Identity in Early Medieval Britain.* London: Leicester University Press.

Moreno, I. and Piera, J. (2007) Intervenció a la Plaça de l'Església de Granollers 2002-2003: La necròpolis i la sagrera medieval. *III Congrés d'arqueologia medieval i moderna a Catalunya* 1, 233-241.

Mosothwane, M. N. and Steyn, M. (2009) In sickness or in health? Assessment of Early Iron Age human skeletons from Toutswe sites, East Central Botswana. *International Journal of Osteoarchaeology* (19), 66-77.

Mundee, M. (2010a) *Exploring diet and society in medieval Spain New approaches using stable isotope analysis*. PhD. University of Durham

Mundee, M. M. (2010b) An Isotopic Approach to Diet in Medieval Spain. *Food and Drink in Archaeology 2.* Vol. 2. Prospect Books. 64-72.

Márquez-Grant, N., Rissech, C., Casas-Solà, A., Franco, L., Merino, M., Muñoz, V. and Turbón, D. (2012) Un posible caso de hiperostosis esquelética difusa idiopática (DISH)de época tardorromana en la Península Ibérica. In Turbón, D., Fañamás, L., Rissech, C and Rosa, A. (editor) *Biodiversidad humana y evolución.* Barcelona: Purpurink. 345- 348

Müldner, G. and Richards, M. P. (2005) Fast or feast: reconstructing diet in later medieval England by stable isotope analysis. *Journal of Archaeological Science* 32 (1), 39-48.

Müldner, G. and Richards, M. P. (2007a) Diet and diversity at later medieval Fishergate: The isotopic evidence. *American Journal of Physical Anthropology* 134 (2), 162-174.

Müldner, G. and Richards, M. P. (2007b) Stable isotope evidence for 1500 years of human diet at the city of York, UK. *American Journal of Physical Anthropology* 133 (1), 682-97.

Müldner, G. H. (2009) Investigating medieval diet and society by stable isotope analysis of human bone In Gilchrist, R. and Reynolds, A. (editors) *Reflections: 50 Years of Medieval Archaeology.* Leeds: Maney. 327-346.

Naik, B., Lobato, E. B. and Sulek, C. A. (2004) Dysphagia, Obstructive Sleep Apnea, and Difficult Fiberoptic Intubation Secondary to Diffuse Idiopathic Skeletal Hyperostosis. *Anesthesiology* 100 (5): 1311-1312.

Nehlich, O., Fuller, B. T., Márquez-Grant, N. and Richards, M. P. (2012) Investigation of diachronic dietary patterns on the islands of Ibiza and Formentera, Spain: Evidence from sulfur stable isotope ratio analysis. *American Journal of Physical Anthropology* 149 (1), 115-124.

Nelson, R. S., Urquhart, A. C. and Faciszewski, T. (2006) Diffuse idiopathic skeletal hyperostosis: a rare cause of Dysphagia, airway obstruction, and dysphonia. *Journal of the American College of Surgery* 202 (6), 938-42.

Nesher, G. and Zuckner, J. (1995) Rheumatologic complications of vitamin A and retinoids. *Seminars in Arthritis and Rheumatology* 24 (4), 291-6.

NHSIC (2013) *Statistics on Obesity, Physical Activity and Diet: England, 2013.*

O'Connell, T. C., Kneale, C. J., Tasevska, N. and Kuhnle, G. G. (2012) The diet-body offset in human nitrogen isotopic values: a controlled dietary study. *American Journal of Physical Anthropology* 149 (3), 426-34.

O'Connor, T. (2014) Livestock and animal husbandry in early medieval England. *Quaternary International* 346 (Supplement C), 109-118.

Ogden, A. (2008) Advances in the palaeopathology of teeth and jaws. In Pinhasi, R. and Mays, S. (editors) *Advances in Human Palaeopathology.* John Wiley & Sons Ltd. 283 - 308.

Ogden, A. R., Pinhasi, R. and White, W. J. (2007) Gross enamel hypoplasia in molars from subadults in a 16th-18th century London graveyard. *American Journal of Physical Anthropology* 133 (3), 957-66.

Ohishi, H., Furukawa, K., Iwasaki, K., Ueyama, K., Okada, A., Motomura, S., Harata, S. and Toh, S. (2003) Role of prostaglandin I2 in the gene expression induced by mechanical stress in spinal ligament cells derived from patients with ossification of the posterior longitudinal ligament. *Journal of Pharmacological and Experimental Therapeutics* 305 (3), 818-24.

Oppenheimer, A. (1942) Calcification and ossification of vertebral ligaments (spondylitis ossificans ligamentosa). Roentgen study of pathogenesis and clinical significance. *Radiology* 8, 160-164

Oppenlander, M. E., Orringer, D. A., La Marca, F., McGillicuddy, J. E., Sullivan, S. E., Chandler, W. F. and Park, P. (2009) Dysphagia due to anterior cervical hyperosteophytosis. *Surgical Neurology* 72 (3), 266-270.

Ortner, D. J. (2003) *Identification of pathological conditions in human skeletal remains.* 2nd edition*.* Academic Press.

Ortner, D. J. and Ericksen, M. F. (1998) Bone changes in the human skull probably resulting from scurvy in infancy and childhood. *International Journal of Osteoarchaeology* 7 (3), 212-220.

Ortner, D. J., Ponce, P., Ogden, A. and Buckberry, J. (2012) Multicentric osteosarcoma associated with DISH, in a 19th century burial from England. *International Journal of Osteoarchaeology* 22 (2), 245-252.

Oxenham, M. F., Matsumura, H. and Nishimoto, T. (2006) Diffuse idiopathic skeletal hyperostosis in Late Jomon Hokkaido, Japan. *International Journal of Osteoarchaeology* 16 (1), 34-46.

O'Connell, T. C. and Hedges, R. E. M. (1999) Isotopic Comparison of Hair and Bone: Archaeological Analyses. *Journal of Archaeological Science* 26 (6), 661-665.

Paja, L., Molnár, E., Ôsz, B., Tiszlavicz, L., Palkó, A., Coqueugniot, H., Dutour, O. and Pálfi, G. (2010) Diffuse idiopathic skeletal hyperostosis – appearance and diagnostics in Hungarian osteoarcheological materials *Acta Biologica Szegediensis* 54 (2), 75-81.

Papakostas, K., Thakar, A., Nandapalan, V. and O'Sullivan, G. (1999) An unusual case of stridor due to osteophytes of the cervical spine: (Forestier's disease). *The Journal of Laryngology & Otology* 113 (01), 65-67.

Patrick, P. (2014) *The 'obese medieval monk': a multidisciplinary study of a stereotype.* Vol. 590. Oxford, England: Archaeopress.

Pauling, L. and Corey, R. B. (1951) The Structure of Fibrous Proteins of the Collagen-Gelatin Group. *Proceedings of the National Academy of Sciences of the United States of America* 37 (5), 272-281.

Pearson, K. L. (1997) Nutrition and the Early-Medieval Diet. *Speculum* 72 (1), 1-32.

Petscavage, J. M., Grauke, L. J. and Richardson, M. L. (2010) Retinoic acid arthropathy: An unusual cause of elbow pain *Radiology Case Report* 5 (3), 427.

Phenice, T. W. (1969) A newly developed visual method of sexing the os pubis. *American Journal of Physical Anthropology* 30 (2), 297-301.

Phillips, D. L. and Gregg, J. W. (2003) Source partitioning using stable isotopes: coping with too many sources. *Oecologia* 136 (2), 261-269.

Pinhasi, R. and Mays, S. (2008) *Advances in human palaeopathology.* Chichester, West Sussex, England ; Hoboken, NJ: John Wiley & Sons.

Pittsley, R. A. and Yoder, F. W. (1983) Retinoid hyperostosis. Skeletal toxicity associated with long-term administration of 13-cis-retinoic acid for refractory ichthyosis. *New England Journal of Medicine* 308 (17), 1012-4.

Pollard, A. M. and Wilson, L. (2001) Global biogeochemical cycles and isotope systematics – How the world works. In Brothwell, D. R. and Pollard, A. M. (editors)

Handbook of Archaeological Sciences. Chichester, UK: John Wiley and Sons. 191 - 201.

Prescher, A. (1998) Anatomy and pathology of the aging spine1Dedicated to Professor Dr med D. Graf von Keyserlingk on the occasion of his 60th birthday.1. *European Journal of Radiology* 27 (3), 181-195.

Privat, K. L., O'Connell, T. C. and Richards, M. P. (2002) Stable Isotope Analysis of Human and Faunal Remains from the Anglo-Saxon Cemetery at Berinsfield, Oxfordshire: Dietary and Social Implications. *Journal of Archaeological Science* 29 (7), 779-790.

Prowse, T., Schwarcz, H. P., Saunders, S., Macchiarelli, R. and Bondioli, L. (2004) Isotopic paleodiet studies of skeletons from the Imperial Roman-age cemetery of Isola Sacra, Rome, Italy. *Journal of Archaeological Science* 31 (3), 259-272.

Prowse, T. L., Schwarcz, H. P., Saunders, S. R., Macchiarelli, R. and Bondioli, L. (2005) Isotopic evidence for age-related variation in diet from Isola Sacra, Italy. *American Journal of Physical Anthropology* 128 (1), 2-13.

Purcell, N. (2003) The Way We Used to Eat: Diet, Community, and History at Rome. *The American Journal of Philology* 124 (3), 329-358.

Quintelier, K., Ervynck, A., Müldner, G., van Neer, W., Richards, M. P. and Fuller, B. T. (2014) Isotopic examination of links between diet, social differentiation, and DISH at the post-medieval Carmelite Friary of Aalst, Belgium. *American Journal of Physical Anthropology* 153 (2), 203-13.

Quirós Castillo, J. A. (2013) Los comportamientos alimentarios del campesinado medieval en el País Vasco y su entorno (siglos VIII- XIV) *Historia Agraria* 59, 13-41.

Quirós Castillo, J. A. (2014) Agrarian archaeology in Early Medieval Europe. *Quaternary International* 346, 1-6.

Ramachandran, G. N. and Kartha, G. (1955) Structure of Collagen. *Nature* 176 (4482), 593-595.

Reale, B., Marchi, D. and Borgognini Tarli, S. M. (1999) A case of diffuse idiopathic skeletal hyperostosis (DISH) from a medieval necropolis in southern Italy. *International Journal of Osteoarchaeology* 9 (5), 369-373.

Redfern, R. (2010) A Bioarchaeological Investigation of Cultural Change in Dorset, England (Mid-to-Late Fourth Century B.C. to the End of the Fourth Century A.D. *Britannia* 39, 161-191.

Redfern, R. C., Hamlin, C. and Athfield, N. B. (2010) Temporal changes in diet: a stable isotope analysis of late Iron Age and Roman Dorset, Britain. *Journal of Archaeological Science* 37 (6), 1149-1160.

Resnick, D. (2002) *Diagnosis of bone and joint disorders.* 4th edition*.* Philadelphia; London: Saunders.

Resnick, D. and Niwayama, G. (1976) Radiographic and pathologic features of spinal involvement in diffuse idiopathic skeletal hyperostosis (DISH). *Radiology* 119 (3), 559-68.

Resnick, D. and Niwayama, G. (1983) Entheses and enthesopathy. Anatomical, pathological, and radiological correlation. *Radiology* 146 (1), 1-9.

Resnick, D., Shapiro, R. F., Wiesner, K. B., Niwayama, G., Utsinger, P. D. and Shaul, S. R. (1978) Diffuse idiopathic skeletal hyperostosis (DISH) [ankylosing hyperostosis of forestier and Rotes-Querol]. *Seminars in Arthritis and Rheumatism* 7 (3), 153-187.

Resnick, D., Shaul, S. R. and Robins, J. M. (1975) Diffuse idiopathic skeletal hyperostosis (DISH): Forestier's disease with extraspinal manifestations. *Radiology* 115 (3), 513-24.

Richards, M. and van Klinken, G. J. (1997) A survey of European human bone stable carbon and nitrogen isotope values In Sinclair, A. G. M., Slater, E. A., and Gowlett , J. A. J. (editors) *Archaeological Sciences 1995.* Oxford: Oxbow Archaeological Monographs.

Richards, M. P. and Hedges, R. E. M. (1999) A Neolithic revolution? New evidence of diet in the British Neolithic. *Antiquity* 73 (282), 891-897.

Richards, M. P., Hedges, R. E. M., Molleson, T. I. and Vogel, J. C. (1998) Stable Isotope Analysis Reveals Variations in Human Diet at the Poundbury Camp Cemetery Site. *Journal of Archaeological Science* 25 (12), 1247-1252.

Richards, P. M. (2000) Human consumption of plant foods in the British Neolithic: Direct evidence from bone stable isotopes In Fairbairn, A. S. (editor) *Plants in Neolithic Britain and beyond.* Oxford: Oxbow. 123-135.

Rissech, C., Pujol, A., Christie, N., Lloveras, L., Richards, M. P. and Fuller, B. T. (2016) Isotopic reconstruction of human diet at the Roman site (1st-4th c. AD) of Carrer Ample 1, Barcelona, Spain. *Journal of Archaeological Science: Reports* 9 (Supplement C), 366-374.

Roberts, C. A. (1989) The human remains from Kingsholm, Gloucester.

Roberts, C. A. and Cox, M. (2003) *Health & disease in Britain: from prehistory to the present day.* Stroud: Sutton.

Roden, C. (2012) *The food of Spain.* Penguin Books.

Rogers, J., Shepstone, L. and Dieppe, P. (1997) Bone formers: osteophyte and enthesophyte formation are positively associated. *Annals of the Rheumatic Diseases* 56 (2), 85-90.

Rogers, J. and Waldron, T. (1995) *A field guide to joint disease in archaeology.* Chichester: Wiley.

Rogers, J. and Waldron, T. (2001) DISH and the monastic way of life. *International Journal of Osteoarchaeology* 11 (5), 357-365.

Rogers, J., Watt, I. and Dieppe, P. (1985) Palaeopathology of spinal osteophytosis, vertebral ankylosis, ankylosing spondylitis, and vertebral hyperostosis. *Annals of the Rheumatic Diseases* 44 (2), 113-120.

Rothschild, B. M. and Heathcote, G. M. (1995) Characterization of gout in a skeletal population sample: presumptive diagnosis in a Micronesian population. *American Journal of Physical Anthropology* 98 (4), 519-25.

Rottoli, M. (2014) Reflections on Early Medieval resources in northern Italy: The archaeobotanical and archaeozoological data. *Quaternary International* (346), 20-27.

Ruas, M.-P. (2005) Aspects of early medieval farming from sites in Mediterranean France. *Vegetation History and Archaeobotany* 14 (4), 400-415.

Salamon, M., Coppa, A., McCormick, M., Rubini, M., Vargiu, R. and Tuross, N. (2008) The consilience of historical and isotopic approaches in reconstructing the medieval Mediterranean diet. *Journal of Archaeological Science* 35 (6), 1667-1672.

Salazar-García, D.C. (2014) Aproximación a la dieta de la población de la Angorrilla. Resultados preliminares de análisis de isótopos estables del carbono y del nitrógeno sobre restos óseos. In Fernández Flores Á., Rodríguez Azogue, A., Casado Ariza, M., Prados Pérez, E. (Eds.) La necrópolis de época tartésica de la Angorrila, Alcalá del Río, Sevilla. Universidad de Sevilla, Secretariado de Publicaciones, 271: 605-616

Sarzi-Puttini, P. and Atzeni, F. (2004) New developments in our understanding of DISH (diffuse idiopathic skeletal hyperostosis). *Current Opinion in Rheumatology* 16 (3), 287-92.

Schadt, C. R., Zic, J. A. and Fuchs, H. A. (2011) Diffuse idiopathic skeletal hyperostosis associated with bexarotene. *Journal of the American Academy of Dermatology.* Vol. 65. United States: 883-4.

Schlapbach, P., Beyeler, C., Gerber, N. J., van der Linden, S., Burgi, U., Fuchs, W. A. and Ehrengruber, H. (1989) Diffuse idiopathic skeletal hyperostosis (DISH) of the spine: a cause of back pain? A controlled study. *British Journal of Rheumatology* 28 (4), 299-303.

Schoeller, D. A. (1999) Isotope Fractionation: Why Aren't We What We Eat? *Journal of Archaeological Science* 26 (6), 667-673.

Schoeninger, M. J. and DeNiro, M. J. (1984) Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 15 (18), 625-639.

Schoeninger, M. J., DeNiro, M. J. and Tauber, H. (1983) Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220 (4604), 1381.

Schulting, R. J. and Richards, M. P. (2002) The Wet, the Wild and the Domesticated: the Mesolithic— Neolithic Transition On the West Coast of Scotland. *European Journal of Archaeology* 5 (2), 147-189.

Schwarcz, H. P. and Schoeninger, M. J. (1991) Stable isotope analyses in human nutritional ecology. *American Journal of Physical Anthropology* 34 (S13), 283-321.

Scull, C. (1993) Archaeology, early Anglo-Saxon society and the origins of Anglo-Saxon kingdoms. *Anglo-Saxon studies in Archaeology and History* 6, 65-82.

Sencan, D., Elden, H., Nacitarhan, V., Sencan, M. and Kaptanoglu, E. (2005) The prevalence of diffuse idiopathic skeletal hyperostosis in patients with diabetes mellitus. *Rheumatology International* 25 (7), 518-21.

Senolt, L., Hulejova, H., Krystufkova, O., Forejtova, S., Andres Cerezo, L., Gatterova, J., Pavelka, K. and Vencovsky, J. (2012) Low circulating Dickkopf-1 and its link with severity of spinal involvement in diffuse idiopathic skeletal hyperostosis. *Annals of Rheumatic Disease* 71 (1), 71-4.

Serjeantson, D. and Woolgar, C. M. (2006) Fish consumption in Medieval England. In Woolgar, C. M., Serjeantson, D., and Waldron, T. (editors) *Food in Medieval England. Diet and nutrition.* New York: Oxford University Press. 102-130.

Shirley, N. R., Wilson, R. J. and Jantz, L. M. (2011) Cadaver use at the University of Tennessee's Anthropological Research Facility. *Clinical Anatomy* 24 (3), 372-380.

Shoulders, M. D. and Raines, R. T. (2009) Collagen structure and stability. *Annual Review of Biochemistry* 78, 929-58.

Sirignano, C., Grau Sologestoa, I., Ricci, P., García-Collado, M. I., Altieri, S., Quirós Castillo, J. A. and Lubritto, C. (2014) Animal husbandry during Early and High Middle Ages in the Basque Country (Spain). *Quaternary International* 346, 138-148.

Slonimsky, E., Leibushor, N., Aharoni, D., Lidar, M. and Eshed, I. (2016) Pelvic enthesopathy on CT is significantly more prevalent in patients with diffuse idiopathic skeletal hyperostosis (DISH) compared with matched control patients. *Clinical Rheumatology* 35 (7), 1823-1827.

Smith, C. F., Pugh, D. g. and Polley, H. F. (1955) Physiologic vertebral ligamentous calcification: An aging process. *American Journal of Roentgenology* (74), 1049-1058.

Smythe, H. and Littlejohn, G. (1998) Diffuse idiopathic skeletal hyperostosis. In Klippel, J. H. and Dieppe, P. A. (editors) *Rheumatology.* 2nd edition. London: Mosby.

Spagnola, A. M., Bennett, P. H. and Terasaki, P. I. (1978) Vertebral ankylosing hyperostosis (forestier's disease) and hla antigens in pima indians. *Arthritis & Rheumatism* 21 (4), 467-472.

Spall, C. A. and Toop, N. J. (2005) *Blue Bridge Lane & Fishergate House, York. Report on Excavations: July 2000 to July 2002* http://www.mgassocs.com/mono/001/index.html

Spencer, C. (2011) *British food: an extraordinary thousand years of history.* London: Grub Street.

Spencer, R. K. (2008) *Testing hypotheses about diffuse idiopathic skeletal hyperostosis (DISH) using stable isotope analysis and aDNA analysis of late medieval Bristish populations*. Doctoral thesis. Durham University.

Standring, S. and Tunstall, R. (2015) *Gray's Anatomy: The Anatomical Basis of Clinical Practice.* 41 edition. Elsevier.

Steffee, W. P., Goldsmith, R. S., Pencharz, P. B., Scrimshaw, N. S. and Young, V. R. (1976) Dietary protein intake and dynamic aspects of whole body nitrogen metabolism in adult humans. *Metabolism* 25 (3), 281-97.

Steinbock, R. (1976) *Paleopathological diagnosis and interpretation: Bone diseases in ancient human populations* Springfield, Ill: Charles C. Thomas

Stone, D. J. (2006) The consumption of crops in the Late Medieval England. In Woolgar, C. M., Serjeantson, D., and Waldron, T. (editors) *Food in Medieval England: Diet and nutrition.* Milton Keynes: Oxford University Press. 11-26.

Storch, M. J., Hubbe, U. and Glocker, F. X. (2008) Cervical myelopathy caused by soft-tissue mass in diffuse idiopathic skeletal hyperostosis. *European Spine Journal* 17 Suppl 2, S243-7.

Subirana i Domènech, M., Cuquerella Fuentes, A., Planchat Teruel, L. M. and Lucena Romero, J. (2002) Restos óseos con Hiperostosis difusa esquelética idiopática ó Hiperostosis Anquilosante Vertebral.Deducciones médico forenses de interés. In *Congreso Virtual 2002.*

Sutro, C. J., Ehrlich, D. E. and Witten, M. (1956) Generalized juxta-articular ossification of ligaments of the vertebral column and of the ligamentous and tendinous tissues of the extremities; (also known as Bechterew's disease, osteophytosis and spondylosis deformans). *Bulletin for the Hospital of Joint Diseases* 17 (2), 343-57.

Sykes, N. J. (2006) From *cu* to *sceap* to *beffe* and *motton.* The management, distribution and consumption of cattle and sheep in medieval England. In Woolgar, C. M., Serjeantson, D., and Waldron, T. (editors) *Food in medieval England: diet and nutrition.* Oxford: Oxford University Press. 56-71.

Tafuri, M. A., Craig, O. E. and Canci, A. (2009) Stable isotope evidence for the consumption of millet and other plants in Bronze Age Italy. *American Journal of Physical Anthropology* 139 (2), 146-153.

Tanaka, H., Nagai, E., Murata, H., Tsubone, T., Shirakura, Y., Sugiyama, T., Taguchi, T. and Kawai, S. (2001) Involvement of bone morphogenic protein-2 (BMP-2) in the pathological ossification process of the spinal ligament. *Rheumatology* 40 (10), 1163-1168.

Tanaka, T., Ikari, K., Furushima, K., Okada, A., Tanaka, H., Furukawa, K., Yoshida, K., Ikeda, T., Ikegawa, S., Hunt, S. C., Takeda, J., Toh, S., Harata, S., Nakajima, T. and Inoue, I. (2003) Genomewide linkage and linkage disequilibrium analyses identify COL6A1, on chromosome 21, as the locus for ossification of the posterior longitudinal ligament of the spine. *American Journal of Human Genetics* 73 (4), 812-22.

Tangrea, J. A., Kilcoyne, R. F., Taylor, P. R. and et al. (1992) SKeletal hyperostosis in patients receiving chronic, very-low-dose isotretinoin. *Archives of Dermatology* 128 (7), 921-925.

Tanishima, S., Takeda, C., Hamamoto, Y., Kondo, Y. and Nagashima, H. (2012) Prompt surgical management for spinal fracture in the elderly aged over 90 years with diffuse idiopathic skeletal hyperostosis to extend their healthy lifespan. *European Journal of Orthopaedic Surgery & Traumatology* 22 (1), 29-34.

Tannahill, R. (1973) *Food in history.* London: Eyre Methuen.

Thibaut i Comalada, E. (2006) *Cuina medieval catalana.* Cossetània Edicions

Thomas, R. (2005) Zooarchaeology, Improvement and the British Agricultural Revolution. *International Journal of Historical Archaeology* 9 (2), 71-88.

Thompson, I. (2015) When was the Roman conquest in Hertfordshire? In Lockyear, K. (editor) *Archaeology in Hertfordshire.* Hatfield, Hertfordshire: Hertfordshire Publications. 117-134.

Trickett, M. A. (2006) *A tale of two cities: diet, health and migration in post-medieval Coventry and Chelsea through biographical reconstruction, osteoarchaeology and isotope biogeochemistry*. PhD. Durham: University of Durham.

Trinkaus, E., Maley, B. and Buzhilova, A. P. (2008) Brief communication: paleopathology of the Kiik-Koba 1 Neandertal. *American Journal of Physical Anthropology* 137 (1), 106-12.

Tsukahara, S., Miyazawa, N., Akagawa, H., Forejtova, S., Pavelka, K., Tanaka, T., Toh, S., Tajima, A., Akiyama, I. and Inoue, I. (2005) COL6A1, the candidate gene for ossification of the posterior longitudinal ligament, is associated with diffuse idiopathic skeletal hyperostosis in Japanese. *Spine (Phila Pa 1976)* 30 (20), 2321-4.

Tsukamoto, Y., Onitsuka, H. and Lee, K. (1977) Radiologic aspects of diffuse idiopathic skeletal hyperostosis in the spine. *American Journal of Roentgenology* 129 (5), 913-8.

Urrutia, J. and Bono, C. M. (2009) Long-term results of surgical treatment of dysphagia secondary to cervical diffuse idiopathic skeletal hyperostosis. *Spine Journal* 9 (9), e13-7.

US Census Bureau (2017) *Annual Estimates of the Resident Population by Single Year of Age and Sex for the United States, States, and Puerto Rico Commonwealth: April 1, 2010 to July 1, 2016*

Utsinger, P. D. (1985) Diffuse idiopathic skeletal hyperostosis. *Clinics in Rheumatic Diseases* 11 (2), 325-51.

Utsinger, P. D., Resnick, D. and Shapiro, R. (1976) Diffuse skeletal abnormalities in forestier disease. *Archives of Internal Medicine* 136 (7), 763-768.

van der Merwe, A. E., Maat, G. J. R. and Watt, I. (2012) Diffuse idiopathic skeletal hyperostosis: Diagnosis in a palaeopathological context. *HOMO - Journal of Comparative Human Biology* 63 (3), 202-215.

van der Veen, M., Livarda, A. and Hill, A. (2007) The Archaeobotany of Roman Britain: Current State and Identification of Research Priorities. *Britannia* 38, 181-210.

van der Veen, M., Livarda, A. and Hill, A. (2008) New Plant Foods in Roman Britain — Dispersal and Social Access. *Environmental Archaeology* 13 (1), 11-36.

van Klinken, G. J. (1999) Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26 (6), 687-695.

Vanderklift, M. A. and Ponsard, S. (2003) Sources of variation in consumer-diet delta 15N enrichment: a meta-analysis. *Oecologia* 136 (2), 169-82.

Vengust, R., Mihalic, R. and Turel, M. (2010) Two different causes of acute respiratory failure in a patient with diffuse idiopathic skeletal hyperostosis and ankylosed cervical spine. *European Spine Journal* 19 Suppl 2, S130-4.

Verlaan, J. J., Oner, F. C. and Maat, G. J. (2007) Diffuse idiopathic skeletal hyperostosis in ancient clergymen. *European Spine Journal* 16 (8), 1129-35.

Vezyroglou, G., Mitropoulos, A. and Antoniadis, C. (1996) A metabolic syndrome in diffuse idiopathic skeletal hyperostosis. A controlled study. *The Journal of Rheumatology* 23 (4), 672-676.

Vidal, P. (2000) A paleoepidemiologic study of diffuse idiopathic skeletal hyperostosis. *Joint Bone Spine* 67 (3), 210-4.

Vidoli, G. M., Steadman, D. W., Devlin, J. B. and Jantz, L. M. (2017) History and Development of the First Anthropology Research Facility, Knoxville, Tennessee. In Schotsmans, E. M., Márquez-Grant, N., and Forbes, S. L. (editors) *Taphonomy of Human Remains: Forensic Analysis of the Dead and the Depositional Environment.* John Wiley & Sons.

Vigil-Escalera Guirado, A., Moreno-García, M., Peña-Chocarro, L., Morales Muñiz, A., Llorente Rodríquez, L., Sabato, D. and Ucchesu, M. (2014) Productie strategies and consumption patterns in the Early Medieval village of Gózquez (Madrid, Spain). *Quaternary International* 346, 7-19.

Villari, N., Fornaciari, G., Lippi, D., Cerinic, M. M., Ginestroni, A., Pellicano, G. and Mascalchi, M. (2009) Scenes from the past: the Medici Project: radiographic survey. *Radiographics* 29 (7), 2101-14.

Villotte, S., Castex, D., Couallier, V., Dutour, O., Knusel, C. J. and Henry-Gambier, D. (2010) Enthesopathies as occupational stress markers: evidence from the upper limb. *American Journal of Physical Anthropology* 142 (2), 224-34.

Vives i Balmaña, E. (1989) La societat catalana medieval: reflexions des de l'antropologia. *Cota zero: revista d'arqueologia i ciència* (5), 72-78.

Waldron, T. (1985) DISH at Merton Priory: evidence for a "new" occupational disease? *British Medical Journal (Clinical research ed.)* 291 (6511), 1762-1763.

Waldron, T. (2009) *Palaeopathology.* Cambridge: Cambridge University Press.

Walker, P. L. (2008) Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology* 136 (1), 39-50.

Waters-Rist, A. L. and Katzenberg, M. A. (2010) The effect of growth on stable nitrogen isotope ratios in subadult bone collagen. *International Journal of Osteoarchaeology* 20 (2), 172-191.

Wearing, S. C., Hennig, E. M., Byrne, N. M., Steele, J. R. and Hills, A. P. (2006) Musculoskeletal disorders associated with obesity: a biomechanical perspective. *Obesity Reviews* 7 (3), 239-250.

Webb, E. C., Honch, N. V., Dunn, P. J. H., Eriksson, G., Lidén, K. and Evershed, R. P. (2015) Compound-specific amino acid isotopic proxies for detecting freshwater resource consumption. *Journal of Archaeological Science* 63, 104-114.

Weinfeld, R. M., Olson, P. N., Maki, D. D. and Griffiths, H. J. (1997) The prevalence of diffuse idiopathic skeletal hyperostosis (DISH) in two large American Midwest metropolitan hospital populations. *Skeletal Radiology* 26 (4), 222-225.

Westerveld, L. A., van Bemmel, J. C., Dhert, W. J., Oner, F. C. and Verlaan, J. J. (2014) Clinical outcome after traumatic spinal fractures in patients with ankylosing spinal disorders compared with control patients. *Spine Journal* 14 (5), 729-40.

Westerveld, L. A., Verlaan, J. J. and Oner, F. C. (2009) Spinal fractures in patients with ankylosing spinal disorders: a systematic review of the literature on treatment, neurological status and complications. *European Spine Journal* 18 (2), 145-156.

White, E. (2000) *Feeding a city : York: the provision of food from Roman times to the beginning of the twentieth century.* Vol. 10. Prospect Books.

White, W. (2004) The Human Bone. In Barber, B., Chew, S., Dyson, T., and White, B. (editors) *The Cistercian Abbey of St Mary Stratford Langthorne, Essex.* London: Museum of London.

Whittaker, D. (2000) Ageing from the dentition. In Cox, M. and Mays, S. (editors) *Human osteology in archaeology and forensic science.* London: Greenwich Medical Media. 83 - 99.

WHO (2002) *The world health report 2002. Reducing risks, promoting healthy life.*

WHO (2016) *Global report on diabetes.* France: http://www.who.int/news-room/fact-sheets/detail/diabetes

Whyte, M. P. and Thakker, R. V. (2009) Rickets and osteomalacia. *Medicine* 33 (12), 70-74.

Wilczak, C. and Mulhern, D. (2012) Co-occurrence of DISH and HFI in the Terry Collection. *International Journal of Osteoarchaeology* 22 (4), 452-459.

Wilkins, J. (2003) Land and Sea: Italy and the Mediterranean in the Roman Discourse of Dining. *The American Journal of Philology* 124 (3), 359-375.

Woolgar, C. M. (2006) Meat and dairy products in late medieval England. In Woolgar, C. M., Serjeantson, D., and Waldron, T. (editors) *Food in Medieval England: Diet and Nutrition.* Oxford: Oxford University Press. 88-101.

Appendix 1: Medical glossary

Apnea: transient cessation of respiration.

Atrial fibrillation: very rapid uncoordinated contractions of the atria of the heart resulting in a lack of synchronism between heartbeat and pulse beat.

Cholesterolemia: presence of cholesterol in blood.

Diabetes mellitus type I or Type I diabetes: condition causing the level of glucose (sugar) in blood to become too high due complete absence of insulin production.

Diabetes mellitus type II or Type II diabetes: condition causing the level of glucose (sugar) in blood to become too high due to insufficient production of insulin. Usually associated with overweight, sedentarism or family history.

Dyslipidaemia: abnormal concentrations of lipids or lipoproteins in the blood.

Dysphagia: difficulty in swallowing.

Hoarseness: rough or harsh voice related to inflammation of the throat and larynx.

Hyperinsulinaemia: presence of excess insulin in blood.

Hyperuricaemia: excess of uric acid in blood.

Glucoregulation: regulation of glucose metabolism.

Hypertension: abnormally high arterial blood pressure.

Left ventricular hypertrophy: excessive development of the left ventricle of the heart.

Myelopathy: disorder of the spinal cord or bone marrow.

Nocturnal dyspnea: difficult respiration during sleep.

Single Nucleotide Polymorphisms (SNPs): variant DNA sequence in which the base of a single nucleotide has been replaced by another base.

Stridor: harsh vibrating sound heard during respiration in cases of obstruction of the air passages.

Uraemia: accumulation in the blood of constituents normally eliminated in the urine that produces a severe toxic condition and usually occurs in severe kidney disease.

Appendix 2: Early stages of DISH development: recording form

Skeleton ID:
Sex:
Age:
Ancestry

SKELETAL MANIFESTATIONS

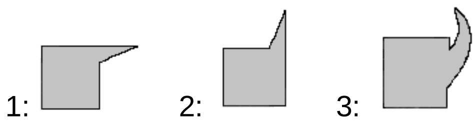
	L	R
C3		
C4		
C5		
C6		
C7		
T1		
T2		
T3		
T4		
T5		
T6		
T7		
T8		
T9		
T10		
T11		
T12		
L1		
L2		
L3		
L4		
L5		

Type of outgrouth:
- Isolated
- Interlocking
- ankylosed

Types of outgrowth:

Location	Type

Types of outgrowth:

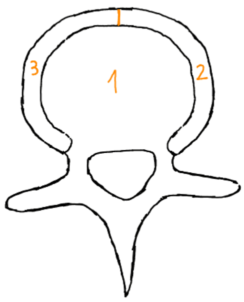


Location example: C3-SR: C3 superior 1/3 right side

Co-location of disc degeneration areas:

Vertebra	Location	Degree of degeneration	Co-location with outgrowth

Location:



Degree of
1- No degeneration
2- Microporosity
3- Microporosity with erosion
4- Macroporosity

Co-location with outgrowth:
1- No overlapping
2- Less than 50% overlapping
3- Complete overlapping

EXTRA-SPINAL MANIFESTATIONS

Location	Presence of element	Size		Comments
		Right	Left	

Presence of element: bilateral, right or left

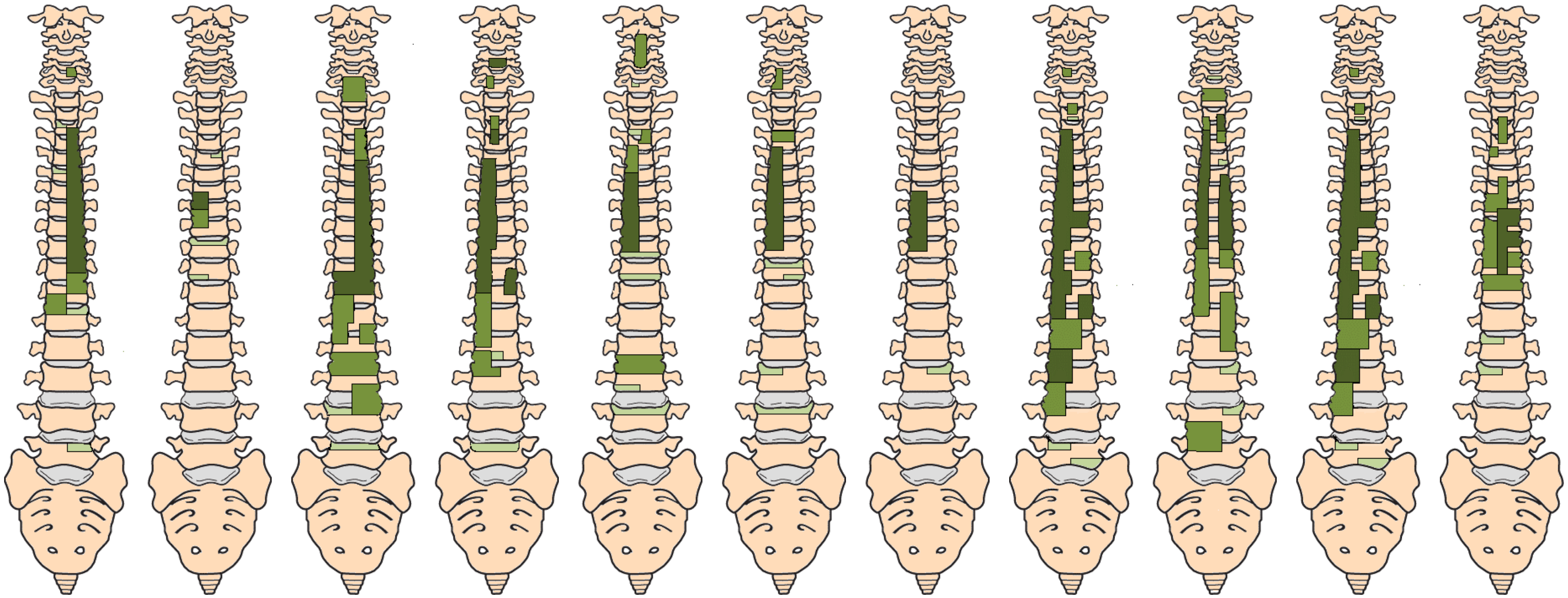
OSSIFICATION OF THE LIGAMENTUM FLAVA

Area present	
With ossification	
Without ossification	

OTHER PATHOLOGY

Appendix 3: Results Part A: Supporting tables and figures

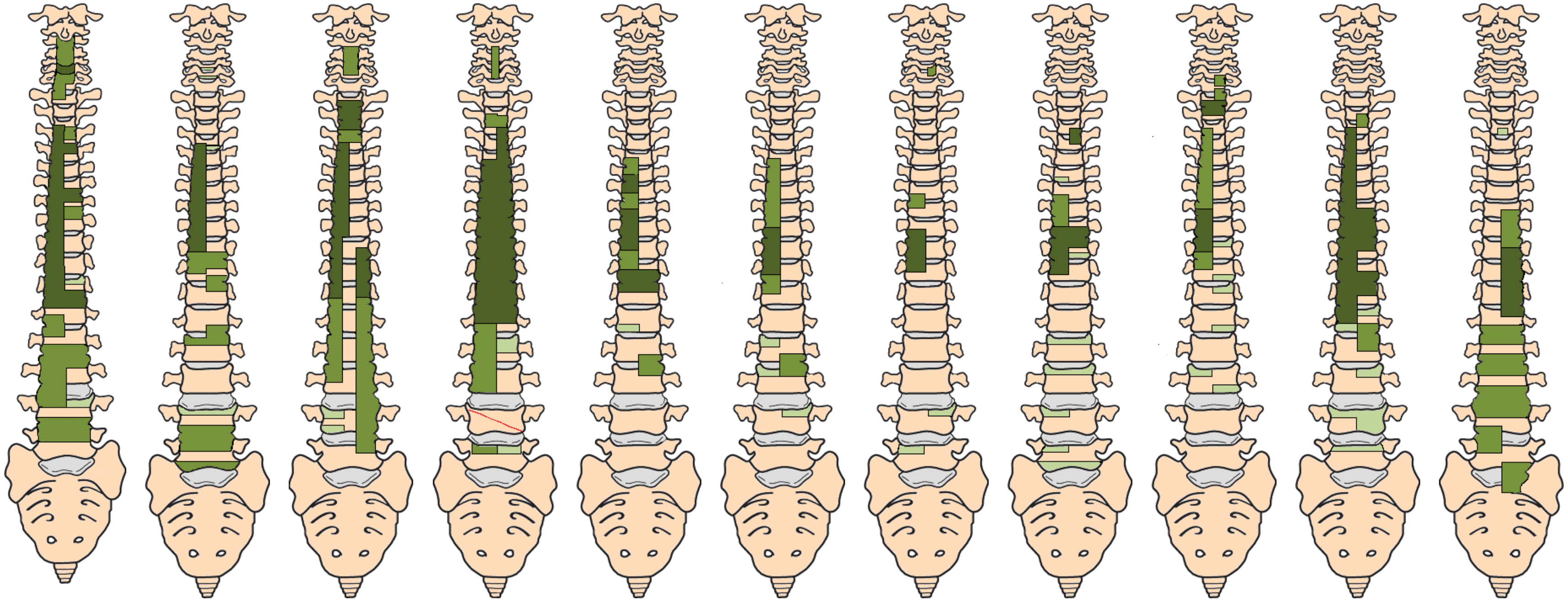
3.1 Distribution of the vertebral ossifications and discarthrosis in the individuals with DISH from the WM Bass Donated Skeletal Collection



ID	1	2	3	4	5	6	7	8	9	10	11
Sex	M	M	M	M	M	M	M	M	M	M	M
Age	51	52	54	55	56	56	57	61	61	61	63
Ancestry	W	W	M	W	W	W	W	W	W	W	W

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black.

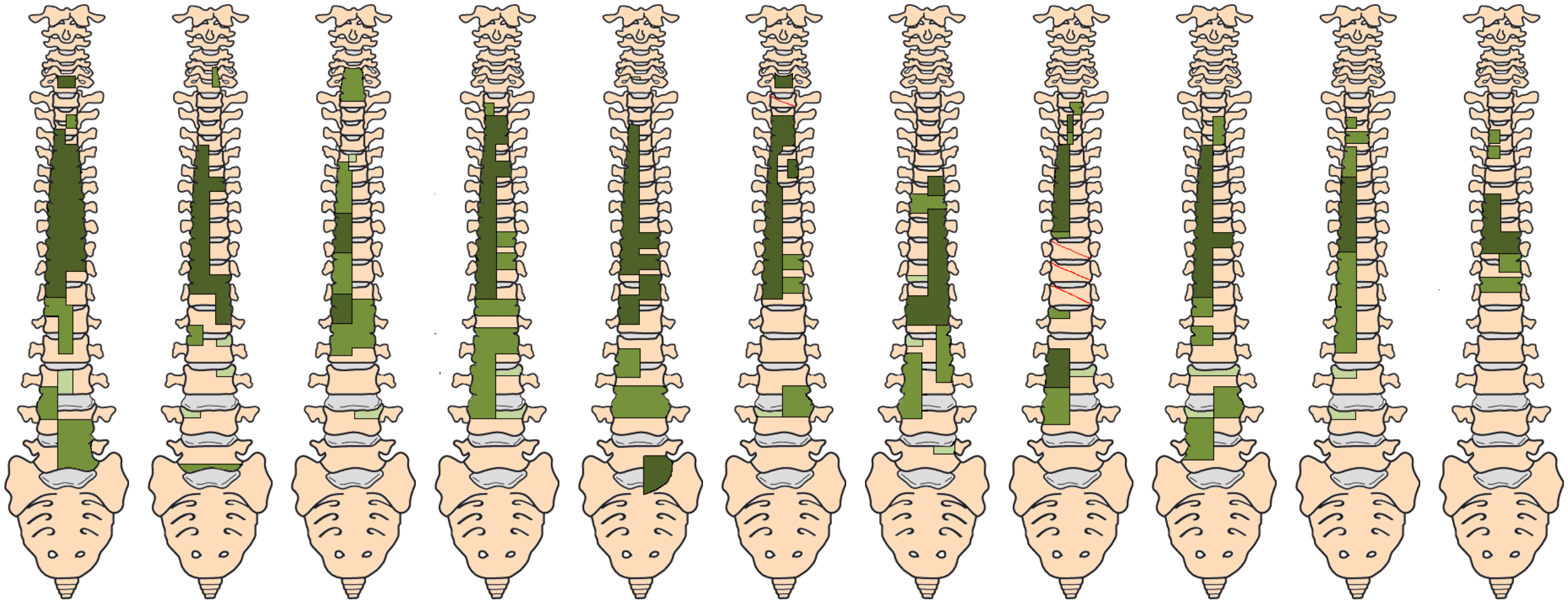
Colour code:  Isolated outgrowths;  Touching outgrowths;  Ankylosed outgrowths



ID	12	13	14	15	17	18	20	21	22	23	24
Sex	M	M	M	M	M	M	M	M	M	M	M
Age	63	64	65	66	67	68	69	71	71	71	72
Ancestry	W	W	W	W	W	W	W	B	W	W	W

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black.

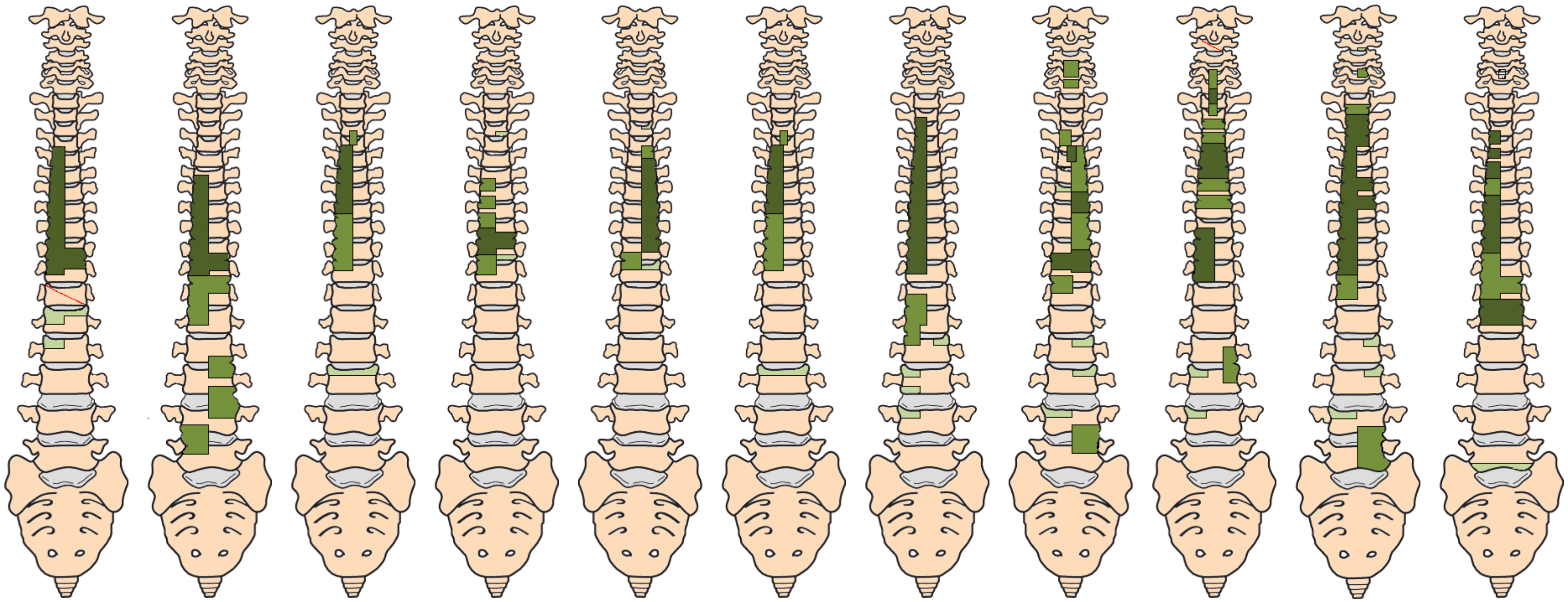
Colour code: Isolated outgrowths; Touching outgrowths; Ankylosed outgrowths



ID	26	27	30	31	32	33	34	36	37	38	39
Sex	M	M	M	M	M	M	M	M	M	F	F
Age	73	75	78	79	81	81	81	88	89	55	61
Ancestry	W	W	W	W	W	W	W	W	W	W	W

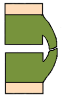
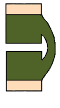
Legend: Sex: M: male, F: female; Ancestry: W: white, B: black.

Colour code:  Isolated outgrowths;  Touching outgrowths;  Ankylosed outgrowths



ID	40	42	43	44	45	46	47	48	50	51	52
Sex	F	F	F	F	F	F	F	F	F	F	F
Age	63	67	68	69	75	75	77	80	82	84	89
Ancestry	W	W	W	W	W	W	W	W	W	W	W

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black.

Colour code:  Isolated outgrowths;  Touching outgrowths;  Ankylosed outgrowths

3.2 Data obtained from the analysis of the WM Bass Donated Skeletal Collection: spinal lesions

ID	Sex	Age	Ancestry	Ankylosed vertebrae	Vertebrae involved	Interlocking	Isolated
1	M	51	W	9 (9)	T3-T11	3	4
2	M	52	W	2 (2)	T7-T8	1	4
3	M	54	W	8 (8)	T5-T12	11	0
4	M	55	W	12 (2 + 2 + 8)	C4-C5 ; T3-T4 ; T5-T12	5	3
5	M	56	W	5 (5)	T6-T10	3	9
6	M	56	W	6 (6)	T5-T10	5	0
7	M	57	W	4 (4)	T7-T10	0	1
8	M	61	W	13 (11 + 2)	T3-L1 ; L2-L3	6	3
9	M	61	W	9 (2 + 8)	T2-T3 ; T3-T10	10	4
10	M	61	W	6(6)	T6-T11	7	5
11	M	63	W	4 (4)	T8-T11	8	2
12	M	63	W	13 (2 +11)	C5-C6 ; T3-L1	12	1
13	M	64	W	7 (7)	T4-T10	5	5
14	M	65	W	9 (9)	T4-T12	8 + 6 cerv. bridges	2
15	M	66	W	11 (11)	T3-L1	8	2
17	M	67	W	7 (2 + 3 + 2)	T6-T7 ; T8-T10 ; T11-T12	4	0
18	M	68	W	3 (3)	T9-T11	5	1
20	M	69	W	3 (3)	T9-T11	2	2
21	M	71	B	5 (2 + 3)	T3-T4 ; T9-T11	2	10
22	M	71	W	5 (2 + 3)	T1-T2; T8-T10	8	4
23	M	71	W	11 (11)	T3-L1	2	8
24	M	72	W	4 (4)	T10-L1	2	1
26	M	73	W	12 (2 + 10)	C6-C7 ; T3-T12	6	2

27	M	75	W	9 (9)	T4-L1	4	3
30	M	78	W	5 (3 + 2)	T8-T10 ; T12-L1	11	2
31	M	79	W	11 (11)	T2-T12	8	2
32	M	81	W	11 (9 + 3)	T3-T11 ; T11-L1	1	2
33	M	81	W	13 (2 + 11)	C6-C7 (T1 missing) ; T2-T12	1	1
34	M	81	W	8 (2 + 6)	T6-T7 ; T8-L1	6	1
36	M	88	W	10 (2 + 6 + 2)	T2-T3 ; T4-T9 ; L1-L2	5	1
37	M	89	W	9 (9)	T4-T12	6	0
38	F	55	W	5 (5)	T6-T10	9	2
39	F	61	W	4 (4)	T7-T10	5	0
40	F	63	W	8 (8)	T4-T11	0	3
42	F	67	W	6 (6)	T6-T11	3	0
43	F	68	W	5 (5)	T6-10	1	0
44	F	69	W	2 (2)	T9-T10	4	2
45	F	75	W	6 (6)	T5-T10	3	2
46	F	75	W	5 (5)	T4-T8	4	2
47	F	77	W	10 (10)	T2-T11	2	5
48	F	80	W	6 (2 + 2 + 2)	T4-T5 ; T7-T8 ; T10-T11	12	4
50	F	82	W	8 (2 + 3 + 3)	C7-T1 ; T4-T6 ; T9-T11	5	2
51	F	84	W	10 (10)	T2-T11	5	4
52	F	89	W	6 (4 + 2)	T7-T10 ; T12-L1	4	2

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black. Ankylosed vertebrae: number of vertebrae involved in the ankylosis. In brackets, the different blocks if applicable. Vertebrae involved: vertebrae involved in the main ankylosis. Interlocking; number of vertebrae showing interlocking vertebral outgrowths. Isolates: number of vertebrae showing isolated outgrowths.

3.3 Data obtained from the analysis of the WM Bass Donated Skeletal Collection: extra-spinal data

ID	Sex	Age	Ancestry	R Ulna	L Ulna	R Patella	L Patella	R Calcaneus	L Calcaneus
1	M	51	W	smooth	2.3	11.3-14.5	10-13.8	17	8-10
2	M	52	W	spicules	5.6	22.4	15.8	12.4	10.9
3	M	54	W	spicules	spicules	4.6	-	-	2.8
4	M	55	W	spicules	spicules	6	5.4	7.7	9.8
5	M	56	W	smooth	smooth	15.5	4.8	5.5	3.4
6	M	56	W	1.6	3.5	16.9	13.8	13.8	7.4-14.3
7	M	57	W	spicules	smooth	spicules	spicules	uneven	uneven
8	M	61	W	uneven	spicules	5	14.1	7.9	9.5
9	M	61	W	spicules	smooth	7.3-9.8 (U)[1] - 13.8 (D)[2]	12.5 (U) - 11.5 (D)	7.3	5.6-9.5
10	M	61	W	spicules	spicules	-	-	-	-
11	M	63	W	spicules	spicules	smooth	uneven	spicules	12.4
12	M	63	W	n.o	7.11	15.9	11.9	15.9	13.6
13	M	64	W	smooth	smooth	2.6	2.6	5.3	5
14	M	65	W	1.3	11.2	-	-	6.5	11.8
15	M	66	W	-	-	17.9 (U), 17.6 (D)	21.4 (U), 10.8 (D)	14.2	18.4
17	M	67	W	smooth	smooth	n.o	n.o	smooth	smooth
18	M	68	W	smooth	smooth	-	7.5	uneven	5.6
20	M	69	W	smooth	smooth	smooth	smooth	uneven	uneven
21	M	71	B	smooth	smooth	uneven	uneven	uneven	uneven
22	M	71	W	spicules	5.6	5.2	4.1 (U) - 11.9 (D)	spicules	spicules
23	M	71	W	spicules	spicules	5.5	uneven	9.5	8.2
24	M	72	W	spicules	spicules	10.9	11.4	8.2	10.8
26	M	73	W	uneven	uneven	10.5	5.9	8.2	7.4
27	M	75	W	1.6	2.9	uneven	uneven	2.2	3.1

30	M	78	W	smooth	smooth	11.1	3.3	2.9	1.6
31	M	79	W	smooth	smooth	smooth	smooth	spicules	spicules
32	M	81	W	smooth	5	3.8	9.8	5.5	6.6
33	M	81	W	uneven	uneven	3.3 (U) - 7.1 (D)	3.5 (U) - 16.1 (D)	4.6	3.3
34	M	81	W	smooth	smooth	smooth	smooth	smooth	smooth
36	M	88	W	1.7	uneven	smooth	smooth	uneven	5.7
37	M	89	W	spicules	1.4	3.8	9.2	6	8.9
38	F	55	W	3.1	4.8	13.6 (U) - 14 (D)	12.3 (U) - 9.3 (D)	17.3	14
39	F	61	W	1.7	3.3	6.4-11-4 (D)	4.4 (D)	uneven	6.8
40	F	63	W	uneven	uneven	smooth	spicules	8.8	8
42	F	67	W	spicules	smooth	-	2.4	2.7	2.3
43	F	68	W	smooth	smooth	13.6-18	10 (U) - 7.8 (D)	14.5-18.4	8.8
44	F	69	W	smooth	smooth	4.3	damaged	damaged	spicules
45	F	75	W	spicules	spicules	3.8	-	damaged	damaged
46	F	75	W	smooth	smooth	4.6	4.6	3.4	spicules
47	F	77	W	-	-	-	-	-	-
48	F	80	W	smooth	smooth	spicules	spicules	5.3	5.3
50	F	82	W	spicules	uneven	9.7 (U) - 9.2 (D)	9.7 (U) - 7.6 (D)	5.2	7.1
51	F	84	W	smooth	smooth	10.5 (U) - 7.1 (D)	9.8	3.9	4.1
52	F	89	W	smooth	smooth	5.2	4.2	6.7	8.6

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black. [1](U): upward enthesopathy; [2](D): downward enthesopathy

2.4 Data obtained from the analysis of the WM Bass Donated Skeletal Collection: pathologies

ID	Diabetes	Obesity	Other diet-related	Cardiopathy	Osteop.[f]	Osteom.[g]	Surgery	Spinal trauma	Other
1	no	no	no	no	no	no	no	T1 healed fracture	
2	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	
3	yes	no	hyperlipidity	HBP[b], 2 heart attacks	no	no	leg amputated	yes	
4	yes	no	no	no	no	no	no	no	
5	no	no	no	no	no	no	hernia	no	
6	no	no	high cholesterol	HTN[c],coronary artery disease	no	no	no	no	Von Willebrands disease
7	no	no	no	ASCVD[d]	no	no	no	no	
8	no	no	no	No	no	no	colon cancer and L lung removal	no	
9	Type 2 DM[a]	No	no	HBP	no	no	appendectomy, cholecystetctomy	no	
10	no	No	no	No	no	no	facial reconstruction	C2-C3 pathological fusion	
11	no	No	no	No	no	no	no	T2-T3 fracture	COPD[h]
12	yes	No	no	No	no	no	craniotomy	no	brain aneurism
13	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	
14	yes	No	no	ASCVD	no	no	amputation of L MT2 and MT3	no	
15	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	
17	no	no	no	No	no	no	open cholecystectomy	no	
18	no	no	high fat diet	Heart disease	no	no	no	no	
20	no	no	no	No	no	no	no	no	
21	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	
22	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	n.m.i	C3-C4 fused, C1 healed cut/fracture	

23	no	no	high cholesterol	HTN	no	no	appendectomy	No	
24	Type 2 DM	no	no	irregular heart beat	no	no	no	T3 fracture, L1 separate tranverse process	COPD & GSW[i]
26	no	no	anemia	No	no	no	appendectomy, lung, hemmroid	no	renal disease
27	no	no	No	HBP	no	no	multiple	no	
30	no	no	No	HBP	no	no	no	no	
31	Type 2 DM	no	no	Yes	no	no	no	no	
32	no	no	no	No	no	no	no	no	lupus
33	no	no	no	ASCVD	no	no	no	no	
34	no	no	no	No	no	no	gall bladder removal	T2-T3 and L2-L4 fracture	
36	no	no	no	irregular heart beat	no	no	no	no	
37	no	no	no	no	no	no	no	no	
38	Yes	no	no	no	no	no	ear	no	
39	Yes	no	no	no	no	no	open heart surgery	no	
40	Yes	morbid	no	yes	no	no	gastric bypass	no	
42	Yes	morbid	no	congestive heart failure, pacemaker	no	no	no	no	
43	no	no	no	HBP	no	no	brain	no	
44	no	no	no	No	no	no	yes	no	
45	no	no	no	several minor heart attacks	no	no	hysterectomy	no	
46	no	no	no	HTN	no	no	several	no	DDD and sponylolysthesis
47	Yes	no	no	HBP, CPA[e]	no	no	no	lumbar lesions	HFI[j]
48	no	no	no	No	no	no	no	Fractured L1	
50	no	no	no	no	no	no	appendectomy	no	
51	no	no	no	congestive heart failure	no	no	no	no	
52	yes		no	no	yes	no	no	no	

Legend: Sex: M: male, F: female; Ancestry: W: white, B: black. N.m.i: no medical information; [a]Type 2 DM: type 2 diabetes mellitus; [b]HBP: high blood pressure; [c]HTN: hypertension; [d]ASCVD: aterosclerotic cardiovascular disease; [e]CPA: cardio pulmonary arrest; [f]Osteop.: osteoporosis; [g]Osteom.: osteomalacia; [h]COPD: chronic obstructive pulmonary disease; [i]GSW: gunshot wound; [j]HFI: hyperostosis frontalis interna

Appendix 4: Inventory form for archaeological human remains

Skeleton ID:
Site:
Time period:

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1. SKELETAL INVENTORY

Element	Side	Preservation	Comments
SKULL			
Frontal	N/A		
Parietal	L		
	R		
Temporal	L		
	R		
Maxilla	L		
	R		
Mandible	N/A		

Element	Side	Preservation	Comments
UPPER LIMBS			
Humerus	L		
	R		
Ulna	L		
	R		
Radius	L		
	R		
LOWER LIMBS			
Os Coxa	L		
	R		
Femur	L		
	R		
Tibia	L		
	R		
Fibula	L		
	R		
Patella	L		
	R		
Calcaneus	L		
	R		
MTT 1	L		
	R		

Skeleton ID: Site: Time period:

Element	Presence	Element	Presence
CERVICAL VER.		T7	
Atlas		T8	
Axis		T9	
C3-C6		T10	
C7		T11	
THORACIC VER.		T12	
T1		**LUMBAR VER.**	
T2		L1	
T3		L2	
T4		L3	
T5		L4	
T6		L5	

2. VERTEBRAL BODY PRESERVATION

	Preservation	Vertebral body	
		Complete	Fragmented
Cervical			
Thoracic			
Lumbar			

3. OFL OBSERVATION

Number of fragments	
Frags with ossification	
Frags without ossification	

4. TEETH INVENTORY

PERMANENT TEETH															
UPPER RIGHT								UPPER LEFT							
18	17	16	15	14	13	12	11	21	22	23	24	25	26	27	28
48	47	46	45	44	43	42	41	31	32	33	34	35	36	37	38
LOWER RIGHT								LOWER LEFT							

Skeleton ID: Site: Time period:

SEX ASSESSMENT RECORDING FORM

Morphological

	Male	**Female**
Subpubic concavity (SBC)		
Ventral arch (VA)		
Medial aspect IP ramus (MA)		
Sciatic notch		
Iliac shape		
Gonial angle		
Mastoid process (MP)		
Occipital protuberance (OP)		
Supra orbital margin (SOM)		
Mental eminence (ME)		
Glabella (G)		

Klales (2012) result (SBC, VA, MA):

Walker (2008) result (MP, OP, SOM, CA, G):

Result sex assessment:

Skeleton ID: Site: Time period:

ADULT AGE ESTIMATION RECORDING FORM

Cranial Sutures	Left/Midline	Right
Coronal Pterica	- 1 2 3 4 5	- 1 2 3 4 5
Sagittal Obelica (midline)	- 1 2 3 4 5	
Lambdoid Asterica	- 1 2 3 4 5	- 1 2 3 4 5
Interpalatine (midline)	- 1 2 3 4 5	
Zygomaticomaxillary	- 1 2 3 4 5	- 1 2 3 4 5

Pubic Symphysis	Left	Right
Symphyseal Relief	- 1 2 3 4 5 6	- 1 2 3 4 5 6
Symphyseal Texture	- 1 2 3 4	- 1 2 3 4
Superior Apex	- 1 2 3 4	- 1 2 3 4
Ventral Symphyseal Margin	- 1 2 3 4 5 6 7	- 1 2 3 4 5 6 7
Dorsal Symphyseal Margin	- 1 2 3 4 5	- 1 2 3 4 5

Iliac Auricular Surface	Left	Right
Superior Demiface Topography	- 1 2 3	- 1 2 3
Interior Demiface Topography	- 1 2 3	- 1 2 3
Superior Surface Morphology	- 1 2 3 4 5	- 1 2 3 4 5
Middle Surface Morphology	- 1 2 3 4 5	- 1 2 3 4 5
Inferior Surface Morphology	- 1 2 3 4 5	- 1 2 3 4 5
Inferior Surface Texture	- 1 2 3	- 1 2 3
Superior Posterior Iliac Exostoses	- 1 2 3 4 5 6	- 1 2 3 4 5 6
Inferior Posterior Iliac Exostoses	- 1 2 3 4 5 6	- 1 2 3 4 5 6
Posterior Exostoses	- 1 2 3	- 1 2 3

Codes: - (missing / not observable); 1-7: as defined in Transition Analysis Manual

Dental Wearing (following Brothwell 1981):

Result age estimation:

Skeleton ID: Site: Time period:

DISH AND CO-MORBIDITIES RECORDING FORM

1 . SKELETAL MANIFESTATIONS

	L	R
Atlas		
Axis		
C3		
C4		
C5		
C6		
C7		
T1		
T2		
T3		
T4		
T5		
T6		
T7		

T8		
T9		
T10		
T11		
T12		
L1		
L2		
L3		
L4		
L5		

Stage of DISH:

Type of outgrouth:

Isolated
Interlocking
Ankylosed

Missing vertebra
Possible vertebra (fragments)

Skeleton ID: Site: Time period:

2. EXTRA-SPINAL MANIFESTATIONS

Location	Presence of element	Size		Comments
		Right	Left	
Ulnae				
Patellae				
Calcanei				

Presence of element: bilateral, right or left

3. CO-MORBIDITIES

Gout:

Osteoarthritis:

Carious lesions:

Scurvy:

Rickets:

Osteomalacia:

Enamel hypoplasia:

Other:

4. ADDITIONAL COMMENTS:

Appendix 5: Dietary characteristics in England and Catalonia through time

In this chapter, the dietary characteristics of England and Catalonia from the Roman to the post-medieval period will be discussed. As it has been extensively noted when describing the aetiology of this disease (section A.1.3), DISH is probably related to metabolic imbalances and therefore potentially related to diet. Thus by exploring the shifts in dietary habits of the past populations, this section aims to give a dietary framework to contextualise the results and provide the grounds to explore the relationship between DISH and diet in ancient populations.

It should be noted that the diet characteristics described herein will draw a general picture of how diet possibly was; however individual and local adaptations to the “model” diet probably existed. Furthermore, while most of the studies highlight the *types* of cereals, meat and vegetables being consumed, there has not been an exhaustive analysis of *how much* each type of food contributed to the entire diet. The dietary information will be combined with the known site characteristics (as described in section B.3.2.2 and B.3.2.3) to draw a more probable type of diet followed by the communities analysed according to their environment.

5.1 Dietary characteristics and isotope data through time in England

Documentary resources and zooarchaeological and isotope data have been brought together to give a more faithful image of the diet in England from the

Roman to the post-medieval period. This sections do not aim to compile all the information published about diet but rather to give a broad image of the diet in each time period in a concise manner. Due to the wealth of research carried out in the British Isles, the information has been tailored to focus on mainland British sites dated as contemporaneous to the sites analysed in here.

5.1.1 Romano-British diet

Rural and urban Romano-British settlements show significant variation in environmental and material culture, possibly reflecting unique community traditions, location, environment and economy as well as the influence of the Roman army, available imports and access to urban markets (King 1999; Redfern et al. 2010). It seems also that only in urban areas, the Roman influence permeated all the social strata; in rural areas, only the aristocracy and the elites, eager the increase their status, adopted the ‘Roman lifestyle’ (Cheung et al. 2012).

5.1.1.1 Archaeological data and documentary sources

In the faunal assemblages, the transition from the Late Iron Age to the Romano-British period is marked by a shift from sheep to mature cattle, pig and poultry (Maltby 1997; King 1999). As this pattern contrasts with the “Roman pattern” typical from central Italian assemblages (i.e. high pig, low cattle and sheep) what possibly influenced the Romano-British diet was not the Roman trends, but the Germanic and Gallic patterns imported by the troops. Hence diet became “militarised” rather than “Romanised” (King 2001). The influence of Italy to the peripheral communities, including Roman Britain, was very weak and local patterns were usually retained; thus the finding of a “Roman pattern” tends to be associated with a high-status very Romanised diet. The higher presence of sheep in rural settlements reflect the Late Iron Age pattern that would be recovered in the post-Roman period (King 2001). Despite the limited archaeological evidence, historical sources suggest dairy products, mainly cheese, made from sheep and goats milk, were very popular. Cheese making tools were widely adopted possibly after the military conquest (Cool 2006: 93).

Poultry was bred for meat and eggs and might have been associated with high status households as they are commonly found in military and villa sites, and are rare rural settlements (Cool 2006: 98, 102). The presence of wild animals in Romano-British assemblages is rare, despite hunting possibly being a popular pastime in Roman Britain (White 2000; Cool 2006: 111). Military sites show a more variable presence of game however their input in diet seems to have been minimal. The association of wild animals, pig and chicken in some sites (e.g. Caerleon (South Wales) and Bishopsgate (London)) (Figure 107), suggests that these meats were possibly part of the elite regime. (Cool 2006: 114).

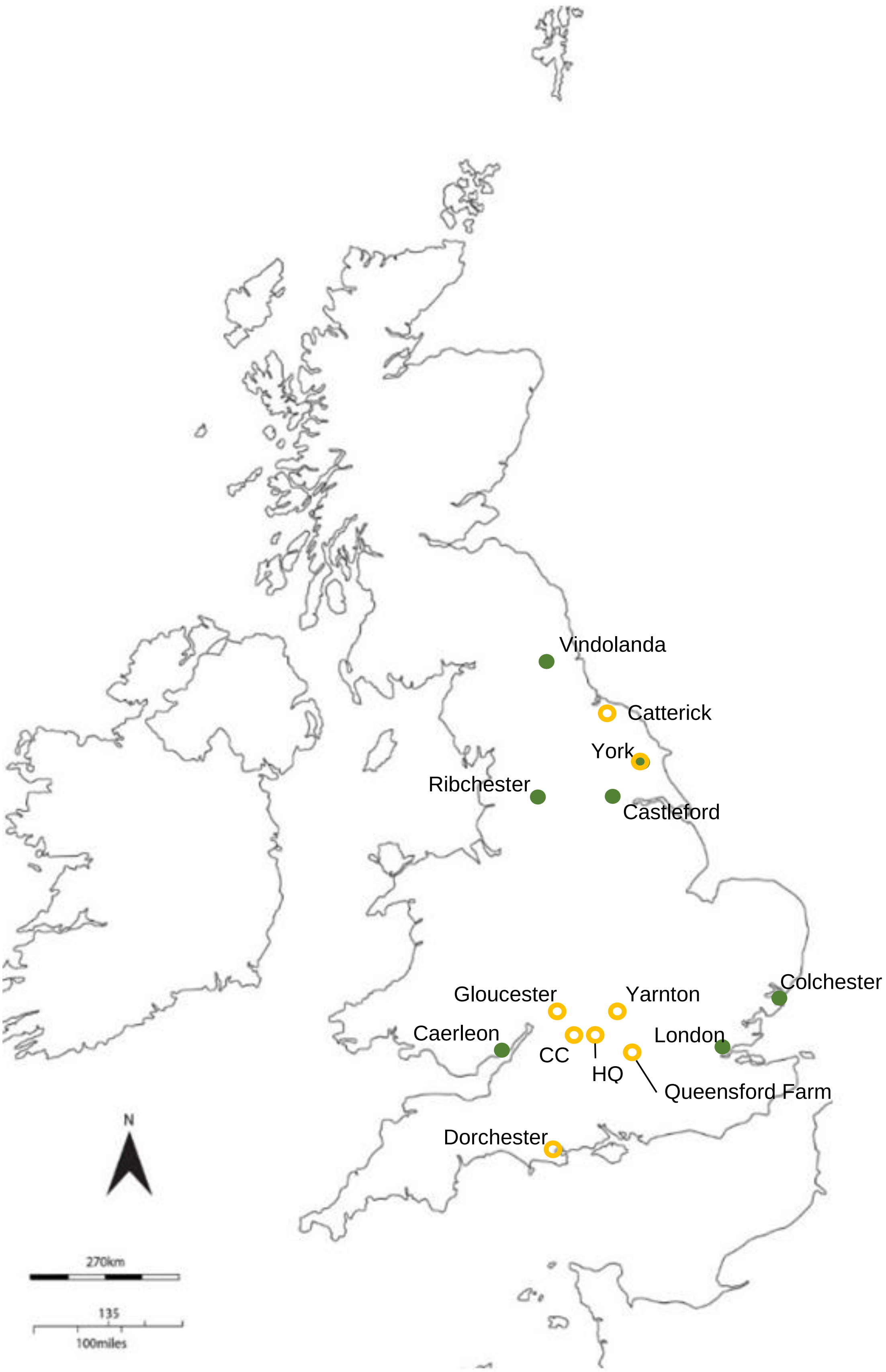


Figure 107: Location of the Romano-British sites mentioned

Legend: ● Faunal assemblages; ○ Stable isotope data

CC: Cotswold Community, HC: Horcott Quarry. Sites in London: Bishopsgate and Southwark

Direct evidence of fish consumption comes from the fish bones assemblages although several problems exist around the recovery of the small bones. In sites where sieving has not been carried out, usually there is a bias towards bigger species (e.g. cod) or no fish at all. In these cases, the findings should be indicative of no bone recovery rather than of no consumption of fish (Locker 2007). Locker (2007) identified regional differences in the consumption of fish depending on the proximity to towns, coastlines and rivers. In short, eel was ubiquitous in all regions, salmonids were more prevalent in the North and the Midlands correlating with the location of the salmon river-systems. Marine flatfishes (e.g. plaice and flounder) were widely represented reflecting their distribution in shallow waters, coastland, shorelines and estuaries. Towns, many of which had military presence, showed the highest concentration of fish bones, reinforcing the hypothesis that Roman influence was stronger in military settlements (King 1999, Locker 2000). The rarity of cod and sturgeon and their association with chicken (e.g. Colchester, Essex) suggests these species were considered a luxury (Cool 2006: 106). Thus the presence of cod in big towns (e.g. London and Southwark) could indicate a localised demand or a reflection of the elite lifestyle as it seems that Romans valued marine fish over freshwater (Locker 2007). Romans also introduced shellfish (Locker 2007) and there is evidence that molluscs (oysters, mussels and cockles) were popular throughout Britain. Oyster shells can be found in urban and rural settlements at a distance of the coast suggesting that, unlike in the Mediterranean area, in Roman Britain, oysters were available to everyone rather than reserved for the elite. Mussel shells have been found in rural inland sites, rural villas and villages (Cool 2006: 106). Fermented fish sauce (e.g.

garum) was possibly considered a luxury item only accessible by the wealthier sections of the society and consumed mainly on high days or holidays (Garnsey 1999: 13; Ejstrud 2006). Its use declined during the 2nd century AD and it use was rare in the Late Roman period (Cool 2006: 62).

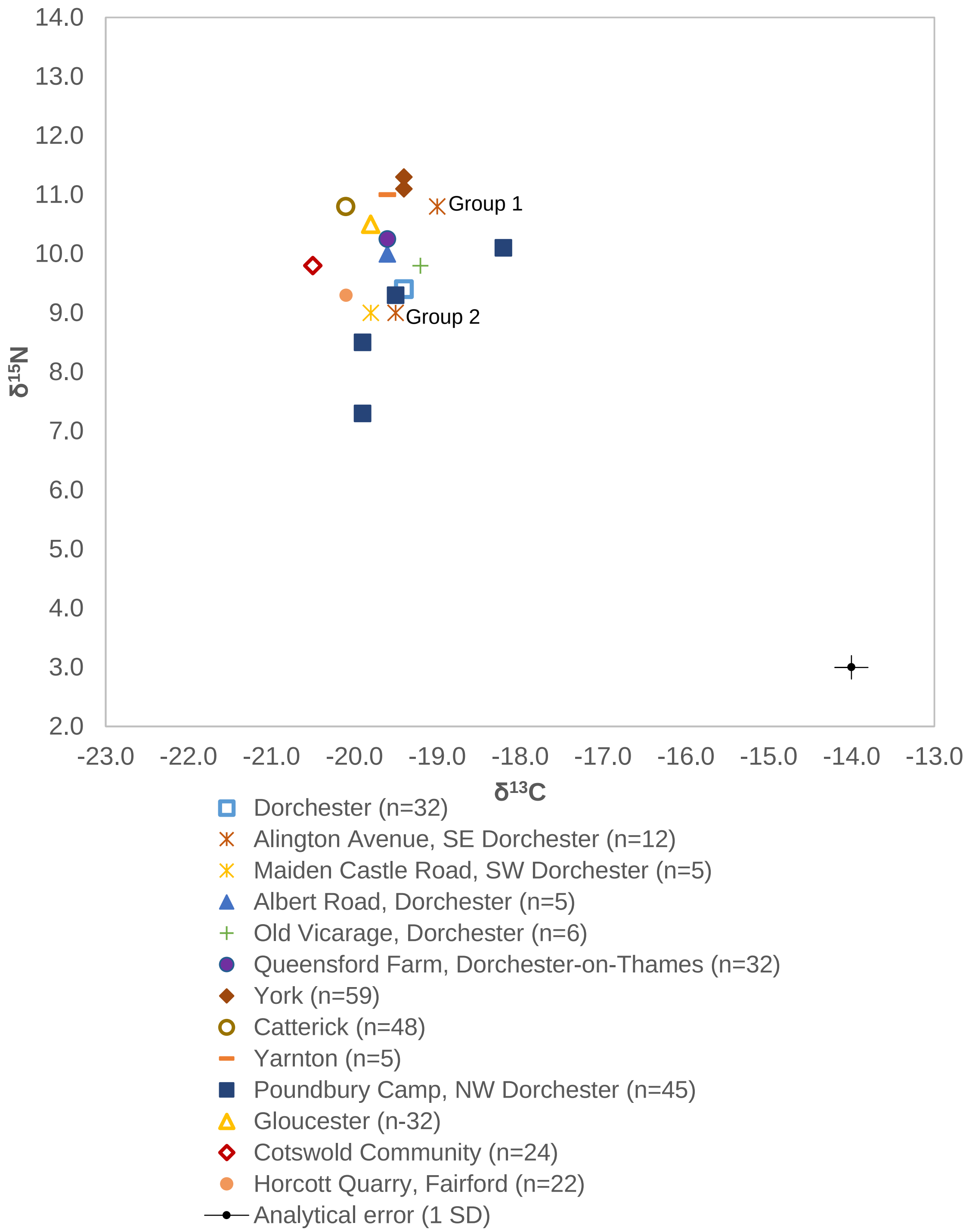
In Britain, wheat was the most important staple food from the Roman to the post-medieval period (White 2000). In Roman Britain, three types of wheat are usually found: emmer (*T. diococcum*), grown in Britain since the Neolithic period, spelt (*T. spelta*), introduced by the first millennium BC, and bread wheat (*T. aestivum*). Barley, oats and rye are also recovered although their presence in assemblages is much smaller (Cool 2006: 69). As in later periods, the whiteness of the bread was directly related to the social status, thus wheat was the most desirable grain and barley was possibly the least desirable. However, barley seems to have been preferred in the northern sites and spelt in the southern and Midlands civilian contexts possibly reflecting the origin of the military forces or the willingness of the native population to adopt the Roman ways (Cool 2006: 77).

During the Roman period, at least 50 new fruits, vegetables and herbs became established in the British diet, diversifying the diet and the farming system and possibly introducing horticulture and arboriculture in the island (Van Der Veen et al. 2007). These new products are primarily found in towns and military sites and their rural distribution strongly depended on the site location – sites by the coast, navigable rivers and major roads show the highest concentration. Fruit and vegetables remains are mainly found in the south-east of the island and there is no evidence of these ingredients in the south-west and the northern regions (van der Veen et al. 2008). However waterlogged deposits from northern and south-western settlements (e.g Castleford (W. Yorks.), Caerleon, Ribchester (Lancs.) and York (W. Yorks.), Figure 122) and the Vindolanda (Northd.) tables indicate imported spices and herbs also reached these regions (Cool 2006: 64).

Olive oil possibly started to arrive in Britain before the conquest (van der Veen et al. 2008) and continued to be distributed throughout Roman Britain at least until the 3rd century AD, however it is not clear whether isolated, small and marginal rural communities used it (Cool 2006: 62). Imported honey was the principal sweetener and may have been available to all levels of society and imported wine probably was also widely available. Finally, barley or spelt beer was drunk by all age groups and segments of the Romano-British society (Cool 2006: 67, 130, 140).

5.1.1.2 Isotopic investigations of diet

The documentary and archaeozoological studies suggest a diet based on cereals, mostly of the wheat family, supplemented with meat (predominantly cattle and pig) and a variable input of fish. Translated to its isotopic signature, it would be expected that $\delta^{13}C$ suggests a C_3-plant based diet and $\delta^{15}N$ a mixed terrestrial and marine resources. Figure 60 shows the results from the average $\delta^{13}C$ and $\delta^{15}N$ values for human remains samples as published in the selected papers.



Graph by author. Data from: Richards et al. (1998), Fuller et al. (2006), Müldner and Richard (2007b), Redfern et al. (2010), Chenery et al. (2011) and Cheung et al. (2012). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 108: Average isotope values for the Romano-British sites referred to in this section

The isotope data from the Dorchester (Dorset) region suggest differences in food consumption between and within communities (Redfern et al. 2010). For example, some individuals from the rural site of Alington Avenue Group 1 showed high carbon and nitrogen isotopic values suggestive of a strong preference for marine resources while Alington Avenue Group 2 and the individuals from the rural site of Maiden Castle Road possibly followed a terrestrial diet (Figure 108). The data from the urban site of Albert Road shows similar nitrogen levels as Group 1 but lower carbon values; a combination strongly suggestive of a terrestrial diet. Despite archaeological and documentary sources suggesting that fish was an integral part diet, in general, nitrogen values do not support evidence for a great increase in the consumption of fish in the Romano-British period. It is, nevertheless, possible that the dietary contribution of freshwater, marine resources or fish-based sauces was relatively small therefore its higher isotopic signature could have been masked by the comparatively large input of terrestrial products in the diet (Redfern et al. 2010). While a variation in the isotope values was expected due to ‘Romanisation’ not reaching equally to all the communities and because diet is influenced by status (Richards et al. 1998; Craig et al. 2009), these results suggest that the degree to which communities were ‘Romanised’ was influenced by social differentiation, access to food and to new and existing dietary patterns (Redfern et al. 2010).

The prominent terrestrial C_3–based diet signal was also captured in teeth and bone samples from Catterick (N. Yorks, Figure 107). The observed average $\delta^{15}N$ difference of 5.1‰ between herbivores and human values was interpreted as a relatively large input of protein or a possible small input of ^{15}N-higher foods (e.g.

pork or freshwater resources) (Chenery et al. 2011). A minor but regular input of marine or anadromous fish (possibly molluscs) was also deduced from the 2.2‰ $\delta^{13}C$ difference observed between the human remains and the herbivore baseline from the Roman York (Müldner and Richards 2007b). Until the 18th century, York had been a tidal port that could be reached by ship via the Ouse River so fish might have been supplied from the Humber Estuary, though it is likely that salmon, locally caught during their annual migration, was more important resource (Alcock 2001). These results are, however, in disagreement with the faunal assemblage where there is a clear predominance of freshwater over marine and anadromous species (Müldner and Richards 2007b).

The data obtained from individuals buried in a 2nd century AD mass burial pit and individuals buried in nearby discreet pits from Roman Gloucester (Gloucs.), suggests a terrestrial C_3-based diet (Figures 107 and 108) (Chenery et al. 2010). The observed difference in the $\delta^{15}N$ average of 4.7‰ and in the $\delta^{13}C$ average of over 2‰ between herbivores and human was interpreted as a high input or animal protein and a small input of marine resources in the diet, respectively (Chenery et al. 2010). In contrast, another study investigating the individuals from Roman Gloucester found that the individuals from the mass graves had significantly lower $\delta^{15}N$ levels compared to those from the single graves, suggesting that the first group ate more animal protein than the second one and hypothesised that this difference possibly resulted from the direct influence of Roman culture to the urban site and their economic status (Cheung et al. 2012).

The results obtained from the urban site of Roman Gloucester, from Gloucester's mass grave and from the rural cemeteries of Horcott Quarry and Cotswold

Community show statistically significant differences between rural and urban populations (Figure 107) (Cheung et al. 2012). The Gloucester individuals show lower $\delta^{13}C$ and higher $\delta^{15}N$ values compared to the individuals from the rural sites (Figure 108), according to the authors, possibly indicative that the individuals from Gloucester consumed a higher proportion of marine and/or freshwater resources while the individuals from the rural cemeteries had a terrestrial C_3-based diet with small inputs of marine resources (Müldner and Richards 2007b; Chenery et al. 2010; Chenery et al. 2011). The individuals from Cotswolds Community showed slightly higher nitrogen values compared to the Horcott Quarry individuals, suggesting that minor dietary differences might have also existed even between rural communities in the form of differential animal protein input.

The Iron Age/Early Roman individuals from Poundbury Camp Cemetery (Dorset) followed a terrestrial omnivorous diet (Richards et al. 1998). The late Roman individuals buried in mausolea and lead coffins showed higher $\delta^{13}C$ and $\delta^{15}N$ values compared to those buried in wooden coffins from the main cemetery suggesting that the more affluent individuals had a more “Roman” diet including marine fish or oysters and fish sauce, while the less affluent individuals had a terrestrial diet without any marine input. The small intra-group isotope value variation observed in the more affluent group indicated that the elite might have followed a similar diet. In contrast, the individuals buried in wooden coffins showed greater carbon isotope variation, expected from an urban population, and a significant variation in the $\delta^{15}N$ values suggestive of variable amounts of protein consumed by each individual (Richards et al. 1998).

Finally, dietary differences between males and females have been reported (Richards et al. 1998; Fuller et al. 2006). For example, the female individuals from Queensford Farm (Oxon. Figure 107) showed a significantly lower nitrogen values compared to males (9.9±0.9‰ and 10.6±0.5‰ respectively) and it was argued that physiological differences (e.g. pregnancy and/or lactation), personal preference, family need or societal values might have influenced this value (Fuller et al. 2006). Chenery and colleague's (2011) results also show that men have more variable, and, in general, show higher carbon isotope values than females. The only adult female with a $\delta^{13}C$ of above -20.0‰ had been buried in an iron-bound coffin and her oxygen isotope values obtained from the biogenic phosphate in the dental enamel suggested a possible foreign origin. Finally, Chenery et al. (2010) found that the higher $\delta^{13}C$, but not the $\delta^{15}N$, in males compared to females was only true in urban sites.

Roman society was a patriarchal structure and it is well known that females did not have the same rights as males in terms of law, property and political status however, it is still unclear if this male/female difference also affected food distribution and portioning (Garnsey 1999). Interestingly, Garnsey (1999) suggested that this difference could reflect men's greater nutritional requirements; hypothesising that food was distributed on the basis of the family needs for survival thus theoretically, the resources were located to the most productive members of the community (Garnsey 1999).

5.1.1.3 Summary

Documentary, archaeological and isotopic data suggest that the diet in the Romano-British time period is dominated by terrestrial resources with a high presence of cattle and pig, which, with poultry and eggs, possibly indicated a high-status diet. Rural settlements show higher presence of sheep/goat, retaining the Late Iron Age dietary pattern and showing a lesser Roman influence. The presence of fish, shellfish and fish sauces in Romano-British sites is unequal and dependant on geographical location and the status of the individuals. However it is possible that the fish/shellfish signature is masked by the overwhelming terrestrial signature. Isotopic data also demonstrates dietary differences between and within urban and rural communities, between social strata and, in some cases, between sexes.

Finally, a $\delta^{15}N$ enrichment of more than 3-4‰ has been usually interpreted as a high input of animal protein in the diet. However this increase is within the range of trophic level increase of 3 to 6‰ (O'Connell et al. 2012; Huelsemann et al. 2013). It is therefore possible that the Romano-British individuals showing higher $\delta^{15}N$ values had the original C_3 terrestrial diet without any extra animal protein input (See Appendix.6.2.4).

5.1.2 English Anglo-Saxon diet

The Anglo-Saxon period extends from the fifth to the eleventh century and is divided into three periods: early (410 to mid-seventh centuries), middle (mid-seventh to mid-ninth century) and late (mid-ninth century to 1066AD) (Kenyon 2006). The subsistence type rural economy characteristic of the early period

(Mays and Beavan 2012) shifted to a more specialised economy aimed to produce an excess of product for exchange starts emerging during the middle period (Pearson 1997; Kenyon 2006; Crabtree 2010). At the same time, nucleated settlements re-appear in the English landscape (O'Connor 2014). Finally, the late Anglo-Saxon period is dominated by a widespread influence of the Christian faith, whose fasting and dietary rules greatly influenced the dietary patterns of both monastic and lay communities (Pearson 1997).

5.1.2.1 Archaeological data and documentary sources

Faunal assemblages from early Anglo-Saxon settlements (e.g. Bishopstone, Bloodmoor Hill and West Stow (Suffolk) and Old Down Farm (Hants.), Figure 109) are dominated by domestic animals, specifically cattle and sheep followed by goat and pig and, to a much lesser extent, wild animals and birds which would have been considered prestige foods (Pearson 1997; Banham 2004: 58; Hagen 2006: 131; Kenyon 2006; Crabtree 2010). Even in the areas dominated by sheep husbandry (e.g. Copsehill Road, Glous), cattle makes up about 35%; a pattern also observed in France and possibly associated to self-sufficiency or a symbol of status, power and wealth (Crabtree 2010). Many middle Anglo-Saxon (*c.* 650 – 850 AD) show an increased specialisation of animal husbandry, reflected in changes in animal ratios, suggesting shift from a self-sufficiency non-specialised system aimed to fulfil the local needs to a more specialised model focused on specific animal products to exchange (Pearson 1997). Thus there is a generalised increase of sheep probably related to the wool and/or milk production (Hagen 2006: 95-96; Crabtree 2010).

The low representation of sheep bone in wealthy states (e.g. Yeavering (Northd.) and Cheddar (Somerset)) compared to relatively poorer sites (e.g. *Hamwich* (Hants.), Skeldergate (York) and Billingsgate Buildings and St Magnus in London) suggest that this meat was not really highly valued. Goat meat seems to have had an even lower value than sheep meat (Hagen 2006: 102). Milk, possibly a seasonal treat, and dairy products (mainly cheese but also butter) from cows, sheep and goats were also consumed (Pearson 1997: 10-11; Banham 2004: 53, 55).

In early Anglo-Saxon assemblages, pig remains typically represent less than 20% (e.g. Old Down Farm and Bishopstone) and, while it is generally associated with poorer classes, its status remains unclear as some wealthy estates kept huge swineherds possibly for commercial reasons. During the early medieval period, historical sources suggest that, on the continent pork, and bacon were considered a feast food and piglets were a luxury food (Banham 2004: 59; Hagen 2006: 116-122). The role of poultry is also unclear because while it was common to keep poultry and it was not considered to be a feast-type food, its time-consuming preparation for cooking was probably not a daily task, at least in a peasant household. Nevertheless, it seems that chicken and capon were prestige foods and hens' and wild birds' eggs a seasonal treat (Banham 2004: 57-58; Hagen 2006: 125).

The Anglo-Saxon population would have had access to seas, rivers and lakes and although it is yet not clear to what extent these were exploited, communities living close to bodies of water possibly took advantage of these resources (Pearson 1997; Banham 2004: 63). The majority of the fish and fisheries-related documentary sources come from monasteries. These suggest that fish, fresh and preserved, was possibly consumed by all strata of society and it was suitable for feasts and for fasting days in the late Anglo Saxon period. ‘Fat fish’ (e.g. whale and porpoise) was possibly considered a delicacy (Hagen 2006: 162-166; Byers 2011). Until the 10th century, Anglo Saxon settlements (e.g. Bishopstone, *Hamwich*, West Stow), produce scarce presence of fish remains and, when found, these are usually freshwater (e.g. carp and pike family) or migratory species (e.g. salmonids and flatfish species). From the 11th century and onwards, the presence of marine species (e.g cod family and herring) increase significantly (Barrett et al. 2004). At the middle and late Anglo-Saxon sites of Durham, Flaxengate (Lincs.), Flixborough (Lincs.), King’s Lynn (Norforlk), Ipswich (Suffolk), Northampton (Northants.) and York Coppergate (W. Yorks.) most of the fish remains were marine (Loveluck 1998; Hagen 2006: 167-169) (Figure 109). Preserved fish, that is salted herring and cod, seems to have reached inland sites (Banham 2004: 66-68).

Seaweeds and sea vegetables (e.g. samphire and scurvy-grass) were possibly also consumed (Banham 2004: 69; Hagen 2006: 52). Traditionally, in the Northern coastal sites, seaweed has been used as fodder for domestic animals (Balasse et al. 2009). At the early Anglo-Saxon site of Bishopstone, seaweed use as fodder was inferred from the presence of small shellfish usually associated with seaweed (Bell 1977). Shellfish would have been available widely throughout the period but its consumption of seem to have varied between sites (Bell 1977).

Cereals, mainly wheat species (emmer, spelt and bread and club wheat) and barley but also oats and rye, consumed eaten or drunk, were main staple food in the Anglo-Saxon diet (Hagen 1999: 20; Banham 2004: 13). The cultivation of wheat increased as the period advanced and was the dominant cereal crop by the 10th century, possibly as a result of taste and because warmer climatic condition facilitated its cultivation (Banham 2004: 14). The consumption of barley declined as the period advanced but since it was needed for brewing, it probably remained the second most common cereal crop (Banham 2004: 13-15). Nevertheless, the use of one crop or another may have varied depending on the local climate and soil characteristics (e.g. oats were grown in harsher upland areas) (Hagen 1999: 17-29; Banham 2004: 16). Pulses were also part of the Anglo-Saxon diet, and peas were possibly mainly eaten by the upper classes (Pearson 1997; Hagen 1999: 33-34; Banham 2004: 29). According to written sources, garden cultivated vegetables (e.g. leeks, onions, garlic, the *brassica* family (e.g. cabbage) and root and green vegetables) were very significant in the Anglo-Saxon diet (Banham 2004: 34). These were supplemented with herbs and possibly fungus, mushrooms and wild greens and plants as these were almost certainly also part of the diet throughout Europe (Pearson 1997; Hagen 1999: 34-44; Banham 2004: 31-38; Hagen 2006: 53). Finally, documentary sources refer to the consumption of fruits, berries and nuts which, because of their seasonality, possibly were considered treats more than staples (Banham 2004: 43).

Honey was the most important sweetener available in the Anglo-Saxon diet and could be turned into the highly-valued mead, a product probably available only to the elite (Banham 2004: 41). Beer remained the most common drink as imported wine was possibly restricted to the upper sections of the society due to its price (Pearson 1997; Banham 2004: 49).

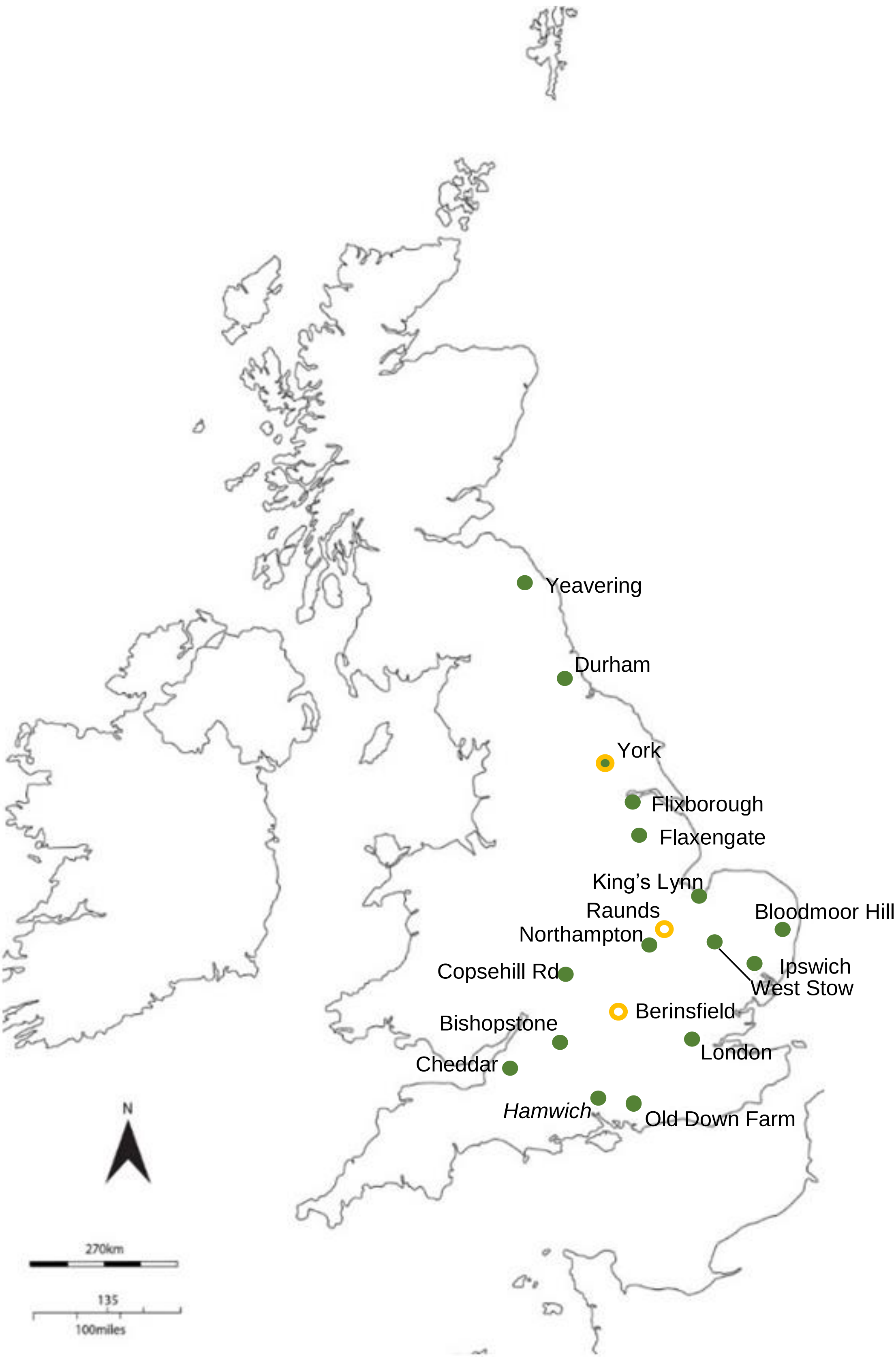


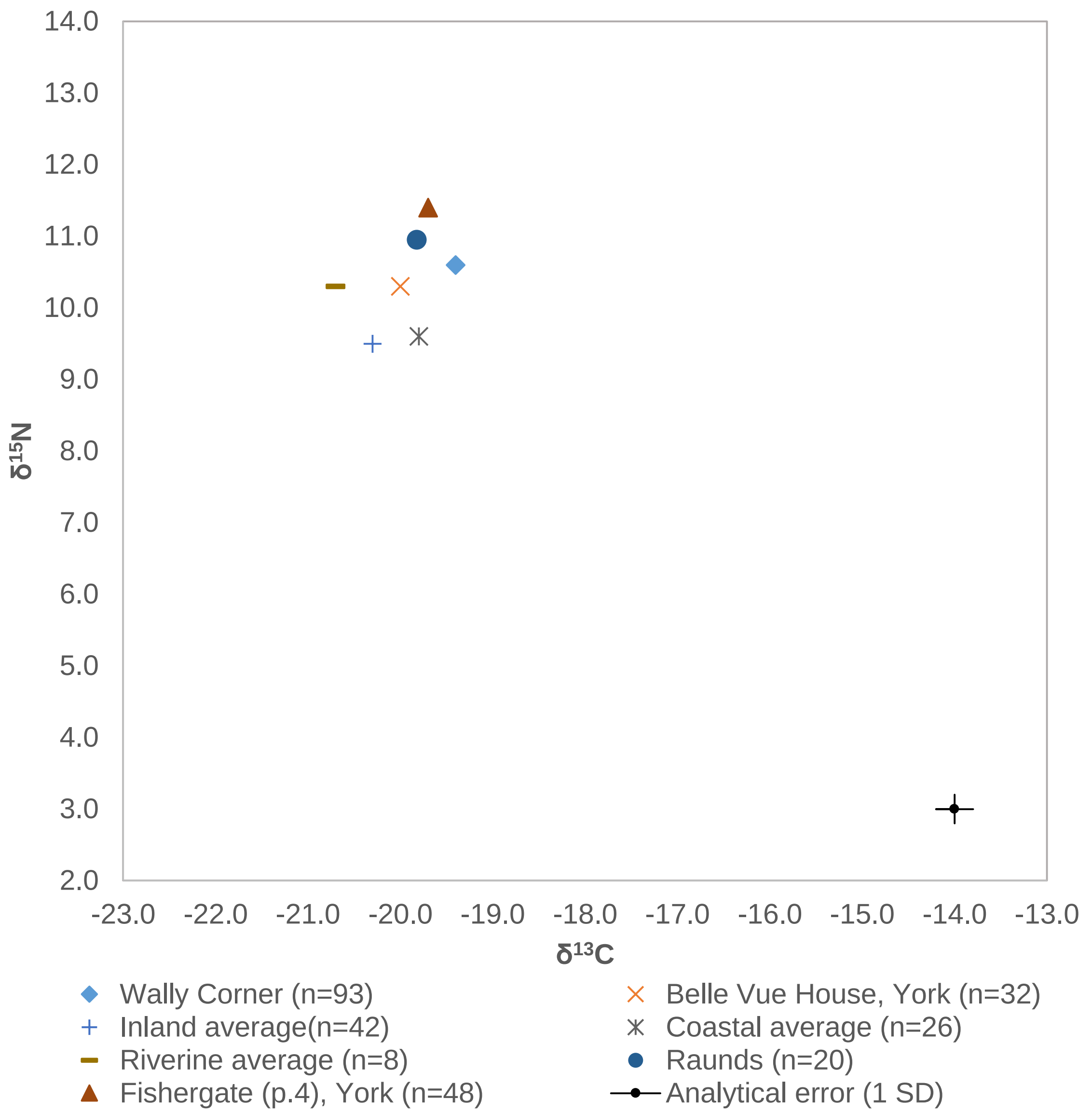
Figure 109: Location of Anglo-Saxon sites mentioned in this section

Legend: Faunal assemblages; Stable isotope data

Sites in London: Billingsgate Buildings and St Magnus. Sites in York: Belle, Vue House, Coppergate, Skeldergate

5.1.2.2 Isotopic investigations of diet

Unlike the Romano-British and the late medieval period, there is a marked lack of stable isotope data on Anglo-Saxon human remains however, most studies concluded that the Anglo-Saxon diet was mainly terrestrial. The observed $\delta^{13}C$ average difference of 1.8‰ between the human remains and the herbivores from the mid-Anglian site Belle Vue House (York, Figures 109 and 110) suggested a completely terrestrial diet without any marine input (Müldner and Richards 2007b). Likewise, the isotope analysis on early Anglo-Saxon human remains from Berinsfield (Oxon.) also indicated a C_3-based terrestrial diet without any marine input. The wide spread of nitrogen values (8.4 to 12.8‰) observed in this site was related to a significant consumption of animal protein, either flesh and/or secondary products (Privat et al. 2002). And for the individuals showing the most higher nitrogen values, it was suggested that their diet might have been supplemented with freshwater animals (fish or birds) or omnivorous animals such as pigs, even though their contemporaneous pig sample produced a herbivorous signal (Privat et al. 2002). The authors argued that a low-class diet with high $\delta^{15}N$ could be explained by the ready available nitrogen-rich resources from the nearby Thame and Thames Rivers and from pigs fed on animal and plant debris; thus arguing that perhaps lower class individuals, whose financial situation did not allow to raise cattle, sheep or goats, raised pigs or exploited the nearby riverine fauna as a free and inexhaustible source of protein (Privat et al. 2002). Similar values were obtained from the adult individuals from the late Anglo-Saxon site of Raunds (Northants.) which suggest that diet was based on C_3 plants and terrestrial protein with a possible small input of freshwater resources. Young adults (18–25 years), middle adults (26–35 years) and old adults (36–45 years) showed similar carbon and nitrogen values (Haydock et al. 2013).



Graph by author. Data from: Privat et al (2002), Müldner and Richards (2007b), Mays and Beavan (2012) and Haydock et al. (2013). The data has been represented as discussed by the authors. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample. Note: the “Inland, coastal and riverine” sites were reported by Mays and Beavan (2012) and are noted in the text.

Figure 110: Average isotope values for the Anglo-Saxon sites referred to in the text

The analysis of inland, coastal and riverine settlements concluded while the diet was generally dominated by terrestrial resources, statistically significant differences between the three groups did exist as a result of a variable inclusion of fish resources (Mays and Beavan 2012) (Figure 110). The carbon and nitrogen values from the coastal sites (Dover Buckland, Mill Hill Deal and St Peter's Broadstairs) possibly reflected the inclusion of marine foods or the use of seaweeds as fodder. Contrary to the expected carbon-nitrogen correlation in the event of an input of marine resources in the diet, there is a lack of correlation between the two isotopes ratios but the authors argued that nitrogen values can be influenced by several, still poorly understood, factors, which could have masked the marine signature in the nitrogen (Mays and Beavan 2012). Compared to the inland sites (Apple Down Compton, Tring Hill Aston Clinton, Barrington Edix Hill, Berinsfield, Coddenham, Dunstan Marina Drive, Ford Laverstock, Galley Hills Banstead Down, Lakenheath Eriswell, Lechlade Butler's Field, Melbourne Water Lane, West Heslerton and Wesgarth Gardens), the riverine settlements (Castledyke South and Ipswich Buttermarket) also showed higher nitrogen values suggesting that these populations consumed freshwater resources (Figure 110). These results were supported by the IsoSource[2] data and the archaeozoological reports which indicated that these assemblages contained more fish remains mostly from freshwater species (Dobney et al. 2007). The IsoSource data estimated that in coastal and riverine sites, fish (freshwater and marine) could contribute as much as terrestrial sources in the

[2] Isosource: Software that allows the quantification of the relative contributions of different food sources to the protein parts of the diet. Phillips, D. L. and Gregg, J. W. (2003) Source partitioning using stable isotopes: coping with too many sources. *Oecologia* 136 (2), 261-269.

diet while in inland communities this type of resources might have contributed a 10% less to the overall diet. This interpretation is in disagreement with the archaeological records although the authors argued “both sources of evidence are subject to interpretation and associated… with large standard deviations” (Mays and Beavan 2012: 873). The authors argued that it was not possible to know whether fish was a regular minor complement to the diet or a fall-back food in times of shortage. Nevertheless the carbon values from coastal populations appear still lower compared to coastal and urban late Medieval settlements suggesting that the consumption of marine resources during the Anglo-Saxon period was significantly less than in the following period. A conclusion which is in complete agreement with the archaeozoological data that indicate an increase of the exploitation of marine sources around 1000AD (Barrett et al. 2004).

Despite the documentary and archaeological evidence suggesting that males and females had different roles in the Anglo-Saxon society, Privat’s et al (2002) results show no significant isotopic difference in carbon or in nitrogen between sexes however dietary differences might have existed but had not been identified by the type of analysis.

5.1.2.3 Summary

Documentary, archaeological and isotopic diet suggest that the Anglo-Saxon diet was dominated by terrestrial resources with heavy reliance on cattle and sheep/goat. Pig does not seem to have been highly considered although its exact position in the diet of the Anglo-Saxon society is still discussed. The limited use of marine and freshwater resources seems to have depended on the proximity to the source although it is very likely that preserved fish did reach the inland settlements. Anglo-Saxon diet also included cereals, mainly were wheat and barley, and a wide variety of pulses, fruit and vegetables.

There is no real consensus on whether Anglo-Saxon diet could fulfil the minimal nutritional requirements. It has been argued that the majority of the people suffered of malnutrition due to the irregular availability of food (Pearson 1997; Hagen 2006) but also that the wide availability of food replacements (i.e. pulses and wild plants) would mean that, despite the shortages, famines would have been rare (Banham 2004: 29). Hodges (1982: 139) also argued that the high food levies collected during the reign of the West Saxon king Ine, could indicate that food was stored to serve as a fall-back resource in times of shortage. It is however possible that both arguments are correct but reflect dietary differences between regions further influenced by social class and ethnic identity (Pearson 1997).

5.1.3 Late medieval English diet

In England, the late medieval is the period between the 11th and the 16th centuries AD and is generally divided between the earlier (11th – 12th centuries) and the later period (13th – 16th centuries). This period is very strongly marked by several famines, the Black Death (1348-49) and the War of the Roses (1455-1487). These episodes not only decimated the population but had a significant impact on agricultural production and in farming strategies and therefore on the Medieval economy. In fact, in the period after the Black Death, survivors of all social status saw an improvement in the quantity and quality of their bread and ale.

Furthermore, the need of provisioning grain for less people also left more land to be used for animal husbandry (Thomas 2005; Stone 2006; Spencer 2011: 70).

5.1.3.1 Archaeological data and documentary sources

As with the previous periods, the late medieval diet was based on cereals, specially wheat, and a variable amount of meat and fish. The diet of the wealthier lay and religious population contained a wide variety of fish and meat, half of the meat consumed was cattle, pork and mutton came in second place and lastly poultry and game birds. Eggs were also part of the diet in the wealthy household however cheese was considered peasants' food and thus not appropriate for the wealthy household (Spencer 2011: 88, 92). The diet of the peasants changed dramatically before and after the Black Death. Prior to the outbreak of the epidemic, their diet was dominated by cereals, mainly bread and ale, supplemented with vegetables, meat was consumed in much lesser quantities and most protein was obtained from fish, dairy and eggs. After the epidemics, meat and ale became more affordable and its consumption increased while the reliance on bread relaxed although its quality increased (Dyer 1988: 92; Spencer 2011: 92). In the period before the Reformation (1529-1533), cows were kept primarily for bearing calves and the extra milk was turned into highly valued (and safer to consume) cheese and butter. The big dairy herds appeared after the Reformation (Spencer 2011: 85).

While it seems that peasant diet was mainly vegetarian, mutton was the most consumed meat. Cattle dominates the urban assemblages (Sykes 2006: 61-63). After the mid-11th century (especially after the Black Death), and in contraposition with the late Anglo-Saxon animal distribution, urban and wealthy population seem to have preferred the tender meat from young animals and the rural communities consumed the older animals (Sykes 2006: 63-64). It is worth noting that the status was signalled not only by the amount and type of meat (e.g. pig and old animals for the peasantry) but also by the cuts of meat and cooking method utilised (Sykes 2006: 71; Woolgar 2006: 92, 93).

Fish was a cornerstone in the late medieval diet however, diverging from the Anglo-Saxon tradition, from the 11th century fish assemblages become dominated by marine fishes, mainly herring and gadids (i.e. cod family). These were available dried or salted coming mostly from the north European fisheries and possibly providing a relatively cheap, easily transported and preserved commodity fitting for the town dwellers (Barrett et al. 2004: 619; Serjeantson and Woolgar 2006: 130). The shift from exploiting freshwater to marine sources from the Anglo-Saxon to the late medieval period has been termed the “fish event horizon” and was possibly related to the decrease in availability of the freshwater species (Barrett et al. 2004: 621, 628). In the 11th – 12th centuries, fishponds as fisheries were built and controlled by the elite (clerical and lay) in what has been considered an active attempt to secure luxurious freshwater fish supplies; however the presence of fishponds in villages might indicate that some freshwater fish was to be sold (Barrett et al. 2004: 628; Serjeantson and Woolgar 2006: 125). Thus the consumption of freshwater fish was, theoretically, limited to the wealthier households however it is also known that some riverine species (e.g. eel) were possibly a significant source of protein to the lower classes (Serjeantson and Woolgar 2006: 127). The imposition of Christian fasting onto the lay population could have also influenced the consumption of marine resources which were allowed in fasting days along with vegetables, grains and pulses (Barrett et al. 2004; Müldner and Richards 2005).

Like in the previous periods, grain still provided the bulk of the caloric intake in the late medieval period (1250 – 1540 AD). It has been calculated that 80% and 65 to 70% of the calories intake from a worker and from the lay nobility, respectively, came from grain (Stone 2006: 11). Wheat again is considered to be the best grain to produce bread however, while before the Black Death it would only been available for the wealthy lay and ecclesiastical lords, and the major part of the population would have eaten bread made of barley, rye, which was more climate resistant, or even of legumes. After the epidemics, peasants increased their consumption of wheat bread (Spencer 2011: 70, 93). Oats were turned into porridge, and ale was made either of barley, oats (more used to brew in the north and the south-west of England) and occasionally, wheat (Stone 2006). It should be noted that bread and porridge have a higher calorie density thus it is possible that, to consume the grain in the most nutritiously efficient way, most rural poor may have not drunk ale at all by the beginning of the 14th century.

Figure 111: Location of the late medieval sites mentioned in this section

Legend: Faunal assemblages; Stable isotope data

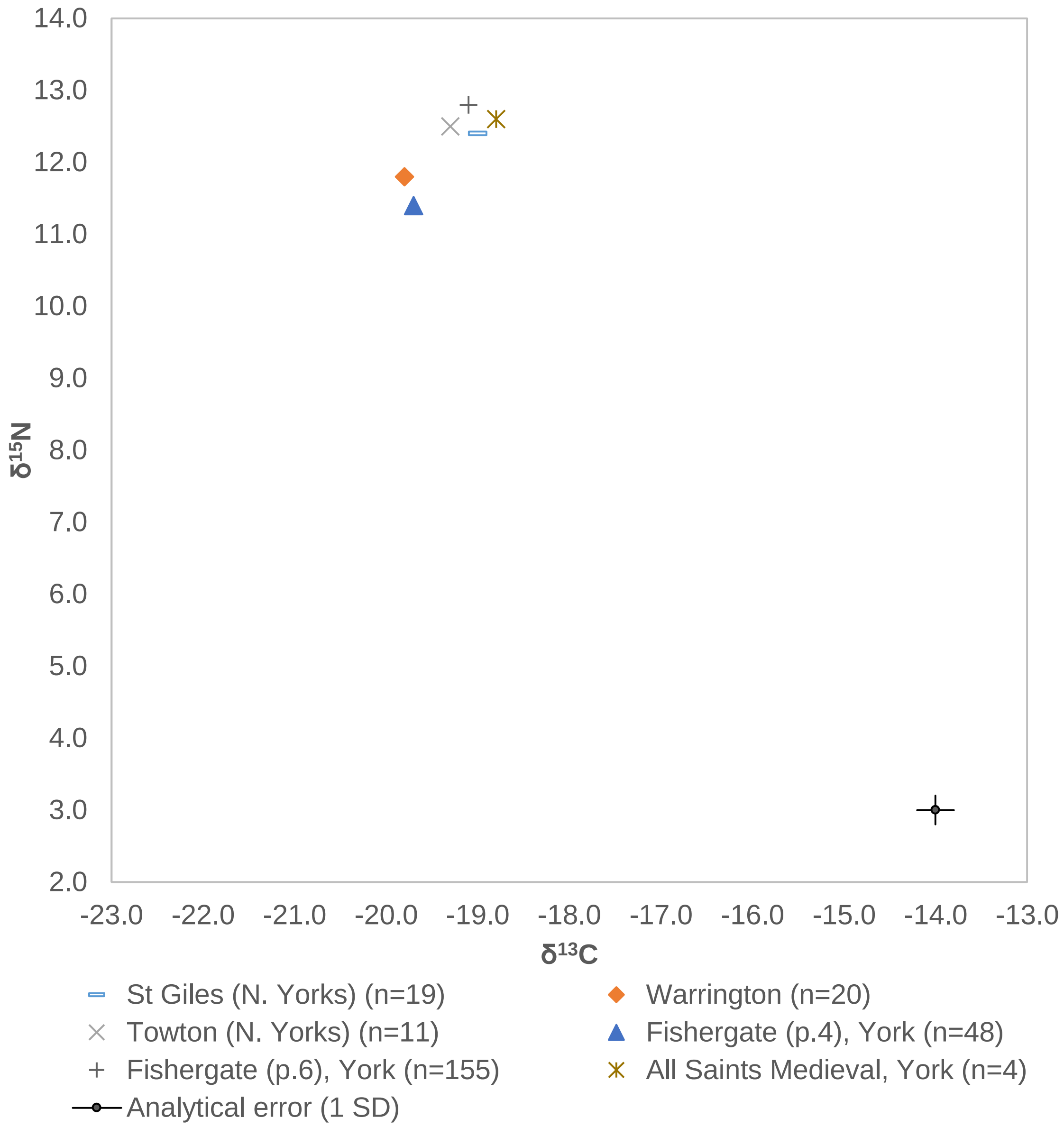
Sites in York: All Saints, Blosson Street, Gilbertine priory of Saint Andrews Fishergate.

Finally, the late medieval period also saw the appearance of small gardens in towns in where vegetables and fruit trees would have been planted and thus contributed to the survival of the owners in terms of shortage. All the vegetables and roots harvested and thus available for consumption in late medieval England were C_3 plants, and while there are records indicating that sugar cane (C_4 plant) was imported from Spain, this would have only been afforded by the wealthier (Spencer 2011: 71, 91)

Thus according to the zooarchaeological data and historic sources, the diet during the late medieval period in England was dominated by C_3 plants. Most of the population obtained their protein from terrestrial secondary products and a strong carbon and nitrogen signal of marine products should be expected as a result of the heavy reliance on this resource throughout the period.

5.1.3.2 Isotopic investigations of diet

The isotope results from the high medieval population of Fishergate (York, N. Yorks.) (p.4, Figure 111 and 112) produced very similar values to those from the Anglo-Saxon population indicating this population also followed a predominantly terrestrial diet. However some individuals show higher $\delta^{13}C$ and $\delta^{15}N$ by 3.8‰ and 9.1‰ respectively, over the herbivore baseline. This suggests that the 11th and 12th centuries were periods of transition in the diet of the population since while a portion of the population does not show any difference from the previous Anglo-Saxon signal, about a third of the population shows a significant increase in the consumption of marine sources with isotope values closer to those exhibited by the late medieval population from Fishergate (p. 6), York (Müldner and Richards 2007b: 691-692). The authors also conclude that this partial adoption of the marine resources suggest that it took decades until this diet was fully adopted by the population (Müldner and Richards 2007b: 693). In the latest part of the medieval period, the high correlation between higher $\delta^{13}C$ and $\delta^{15}N$ suggest a significant input of marine resources in the diet. This is possibly related to the higher adherence to the 215 fasting days in the Christian calendar where meat was banned between a third and a half of the calendar year and fish, fresh or preserved (dried, salted, smoked or pickled) was one of its most popular substitutes (Müldner and Richards 2007b; Spencer 2011: 83).



Graph by author. Data from: Müldner and Richards (2005, 2007a, 2007b). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 112: Average isotope values for the English late medieval sites referenced in the text

Mays (1997) carried out a multi-period dietary which included adult individuals from York Fishergate monastic (n=9) and lay cemeteries (n=10) (1195 – 14th century), Wharram Percy (N. Yorks.) medieval (n=10; 10th – 16th centuries) and post-medieval (n=10; 17th – early 19th century) individuals as well as, possibly lay, benefactors buried in Hartlepool Greyfriars (Durham) (n=10; 13th – 16th centuries), Newcastle Blackfriars (Northd.) (n=9; 13th – 16th centuries) and lay individuals from Scarborough Castle Hill (N. York.) (n=9; 11th – 16th centuries) (Figures 111 and 112). The carbon isotope values vary between -18.17‰ and -20.17‰ suggested a predominantly terrestrial diet complemented with a variable amount of marine resources. The higher carbon values from the individuals buried at the urban site York Fishergate indicate that the monastic community had a stronger reliance on marine resources than the lay individuals who possibly came from a wealthy social strata. The diet of the ordinary peasants from the in- and upland settlement of Wharram Percy also included marine resources possibly at a similar ratio as in the wealthy urban community of Fishergate. These findings agree with the faunal assemblage analysis at Wharram Percy where remains from marine fauna were recovered. The fact that Newcastle and Hartlepool were founded by religious organisations and no separate burial grounds were given to brethren and layfolk, might explain the higher average carbon values for these sites. However as no isotope ratio differences was found between sexes, probably, the carbon difference reflected a coastal-inland difference and not a mixed monastic – lay population (Mays 1997). The faunal assemblages from Scarborough, Hartlepool and Newcastle suggest a fishing industry. Unsurprisingly, the zooarchaeological data suggests that marine resources could have accounted for 10-20% of the Newcastle population's diet. However the isotope data from the Scarborough population suggests a significantly different diet compared to the other two coastal sites (Figure 112).

Mays (1997) argued this could be related to the use of this cemetery by coastal and inland communities which would also explain the greater variation in carbon isotope values within the Scarborough sample.

Keeping in line with the previous studies, the combination of the faunal and human isotope data suggests that the individuals from St. Giles (N. Yorks.), Warrington (Cheshire) and Towton (N. Yorks) followed a mixture of C_3 terrestrial diet, marine and freshwater fish (Figure 112). While this would agree with the riverine location of St Giles and Warrington, the analysis of the faunal assemblage from St Giles produced a significantly more marine than freshwater fish remains. Little variation in the isotope signature from the three different sites was found (Figure 112). This finding was unexpected as the samples represented populations from significantly different social strata and the Towton individuals were the soldiers who died in battle in 1461 and also came from different social backgrounds and geographic locations (Müldner and Richards 2005). In fact, in the study of the population buried at the late medieval Gilbertine priory of St Andrews, Fishergate York (13th – early 16th centuries AD), the isotope data also suggested little differences between the high and the low status individuals. The authors suggested that the availability of cheap sources of protein such as dairy and herring could explain the similar isotope signature between the two groups (Müldner and Richards 2007a).

The examples of studies chosen concur with the archaeological data which indicated that the typical late medieval diet was based on a C_3 terrestrial diet with a growing input of marine resources throughout the period. Furthermore, it seems that this new dietary pattern was adopted by all levels of population. It should be noticed that different sources of protein could produce a similar isotope signature so while different social classes possibly consumed different products, the analysis of stable isotopes in collagen might not be sensitive enough to identify these differences (Müldner and Richards 2005; Müldner and Richards 2007a)

5.1.3.3 Summary

Documentary resources and archaeological and isotopic evidence suggest that late medieval diet was based on cereals, especially wheat, supplemented with vegetables. Meat was consumed in much lesser quantities and most protein was obtained from fish, dairy and eggs. Fish, mainly from marine and to a lesser extent freshwater sources, was an affordable and convenient source of protein that became the cornerstone of the late medieval diet. The prohibition of meat consumption due to the Christian fasting probably influenced the reliance on fish vegetables, grains and pulses. It is finally worth noting that the peasant diet changed significantly after the Black Death as meat and ale became more affordable and thus its consumption increased.

5.1.4 Post-medieval English diet

In British archaeology the period between the 16th and the 19th centuries is known as the post-medieval period. If the late medieval diet was heavily influenced by the fasting rules imposed by the Catholic Church, the post-medieval diet will be influenced by the Reformation and the change in the fasting habits and possibly the consumption of more fish (Müldner 2009). The appearance of market towns and garden markets between the late-16th and the early-17th century and the improvement of the cross-country communications in the 18th and 19th centuries provided a wider variety of foods to the city dwellers (Roberts and Cox 2003: 294; Spencer 2011: 128, 140, 245). Finally, the exploitation of the New World resources in the late 15th century and the Industrial Revolution, changed the food landscape in a way impossible to underestimate. Specifically by the early and mid-19th century, the quality and quantity diet in the over-crowded industrial centres was affected to the level that malnutrition affected almost three-quarters of the inhabitants (Spencer 2011: 267).

5.1.4.1 Archaeological data and documentary sources

During the post-Medieval period, cattle, sheep/goat and pig were the most abundant domesticates. Cattle was reared for meat as well as for milk depending on the county. It seems that the most esteemed of the livestock was mutton, specially sheep (Spencer 2011: 111). By the 16th-17th centuries, while there seems to be a higher regionalisation in the higher prevalence of one or the other species, the prevalence of sheep/goat seems to decrease in favour of cattle possibly because beef and dairy products were considered fashionable and were widely available. Between the 17th and the 18th centuries, the relation between sheep/goat and cattle shifted, with the prevalence of the former increasing at the expense of the latter. In either case, throughout the country, pig was the least abundant of the three domesticates. The versatility of the pig was highly desirable for the peasantry, however it was expensive to rear and so only the wealthy peasants could afford keeping pigs. Nevertheless, by the 17th century, pigs were raised in rural and urban sites. City-raised pigs could roam free in the streets, be fed on table scraps while in the dairy farms they were fed on whey, forage or food scraps (Albarella 2006: 79; Spencer 2011: 112, 150). Between the 18th and 20th centuries the proportion of cattle and sheet/goat remains fairly similar but there is a noticeable increase in the proportion of pig in the faunal assemblages (Gordon 2015: 150). Finally, poultry, chickens and geese and later on also turkeys, were also kept by the peasantry (Spencer 2011: 112).

During the 16th-17th centuries in the West Midlands, where Wolverhampton is located (Figure 113), cattle followed by sheep/goat still dominated the assemblages, however during this period this region had the highest proportion of pigs of all. It seems they were raised in the woodlands and fed on beech mast, roots and acorns although it is possible that, like in the late medieval period, they were fed on lentils, cereals or pasture (Albarella 2006: 77). By the 17th-18th centuries, in the West Midlands sites were still dominated by cattle and sheep/goat with the proportion of pig being slightly decreased (Gordon 2015: 151). Sheep/goat, and more specifically goat, was the most predominant domesticates in high status and ecclesiastical sites and, most importantly, also in industrial sites (Gordon 2015: 160, 166).

Fish had become a cornerstone of the medieval diet due to the Christian dietary restrictions and during the post-medieval period fish continued having an important role in the diet. The highest proportion of fish came from marine sources, followed by migratory and freshwater. However there seems to be a decline in marine and freshwater species and an increase in the migratory fishes. Just as in the previous periods, marine species like cod, whiting, herring and flatfishes are the most abundant. Eel and smelt are the migratory species more widely consumed. Members of the carp family, pike and chub were the most typical freshwater species in this period (Gordon 2015: 174). Anchovies were imported from the Mediterranean region in great quantities and herring, imported from Wales during the 16th and 17th centuries, was a very popular during Lent. Freshwater fish and salmon consumption was most possibly limited to the wealthy while stockfish and dried, salted, pickled or smoked fish would have been widely available and affordable (see Gordon 2015: 112-114 for summary). In the central region of England, most of the species identified are marine, followed by freshwater and finally migratory species (Gordon 2015: 179).

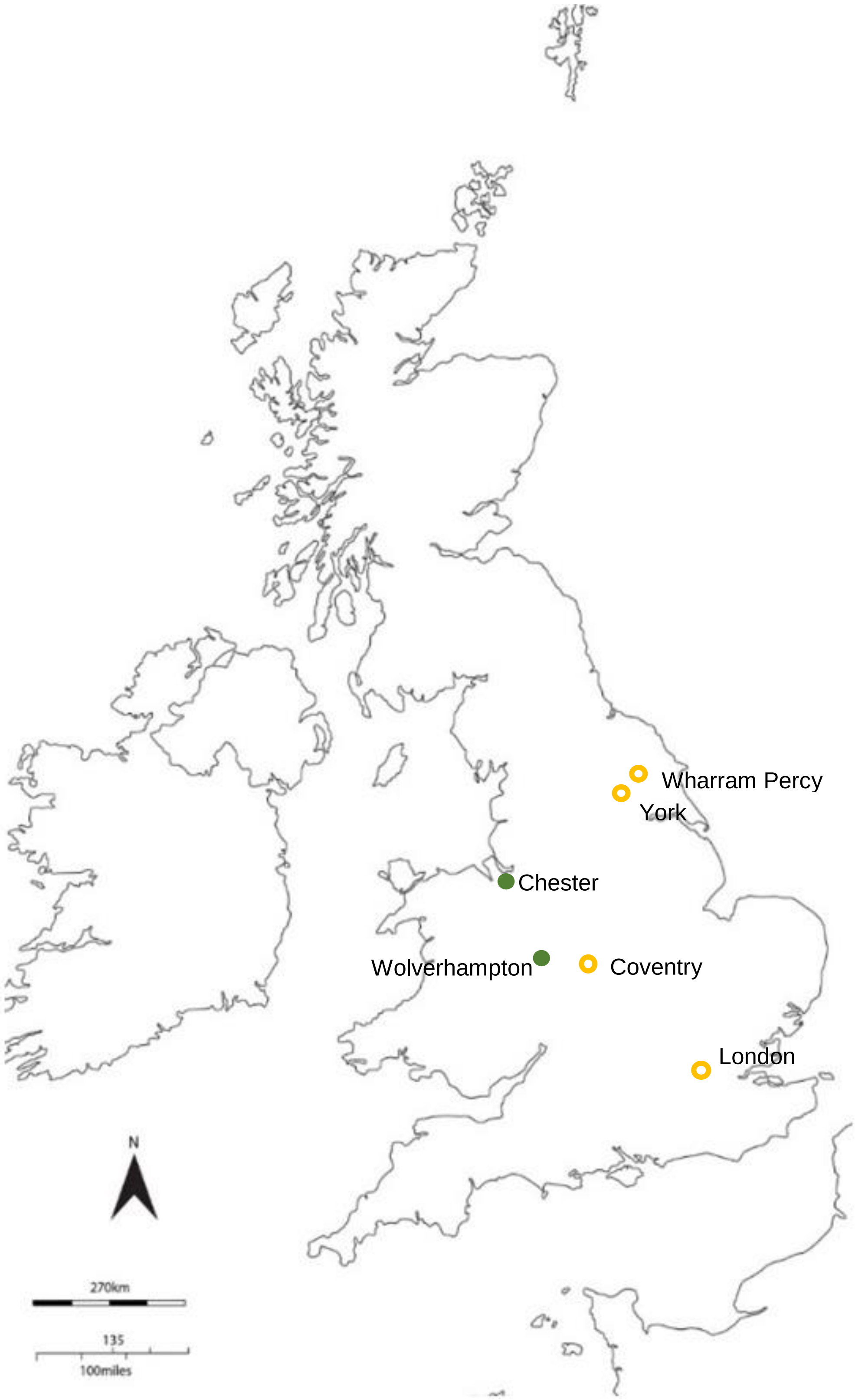


Figure 113: Location of the post-medieval sites mentioned in this section

Legend: ● Faunal assemblages; ○ Stable isotope data
Sites in London: Chelsea, Old Curch; Lukin Street. Sites in York: All Saints

In post-medieval urban Chester (Cheshire, Figure 113), the most abundant animal was cattle which was consumed as veal and beef. In fact Cheshire was a reputable cattle rearing region and by the 17th century it had become a well-known dairy district. Sheep/goat were the second most abundant domesticates which was possibly kept for household consumption. The presence of goat, possibly associated with high-status households, and of pig was very low in this assemblage. Game had a minor contribution to the diet of the inhabitants of Chester. In the assemblages, rabbit was the most prevalent while hare and deer were less abundant possibly because their consumption was limited to the elite (Gordon 2015: 104-105). Chicken and geese were present in the assemblage and it seems both were exploited for meat and eggs (Gordon 2015: 111). The fish remains recovered were mainly of marine and migratory species (e.g. eel, smelt, flatfish, cod and whiting, herring and mackerel). Freshwater fish were less abundant but remains of cyprinids, perch, stickleback and trout were found. Finally, remains from the imported anchovies and stockfish, salmon, haddock, ling and mackerel, known to have been sold in Chester's fish market have also been recovered (Gordon 2015: 112-113).

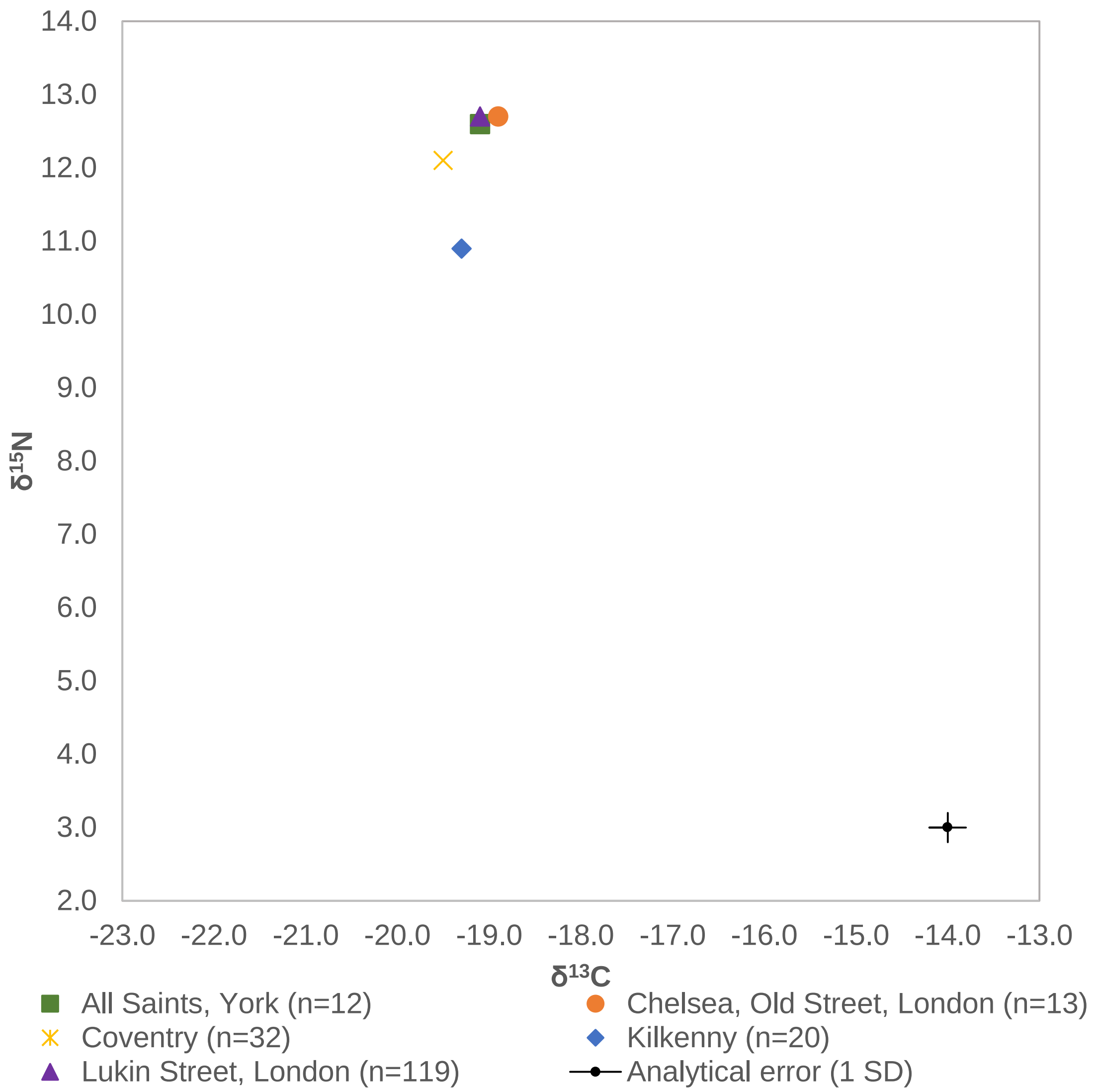
The commonest crops remain the same as in the previous epochs: wheat, rye, barley, oats, beans and peas along with the newly added buckwheat, vetches and lentils mainly used as animal fodder (Spencer 2011: 110). By mid-17th century, the garden markets supplied London and other market towns with cauliflowers, cabbages, radishes, carrots, salads, cucumbers, onions, corn salad, spinach, artichokes, asparagus and even melons. By the end of the century this included potatoes. The production of crop was improved by the use of fertiliser and by growing them on hotbeds (Spencer 2011: 140, 160)

After the return of Columbus from the Americas in the late 15th century, a new range of products arrived to Europe and to the British Isles although it took over a century to incorporate the new products in the English diet (Spencer 2011: 99) The most notable inclusions were potatoes, maize and sugar cane, the last two being C_4 plants which produce a distinctive isotopic signature. Maize was not readily included in the post-medieval English human diet however it was mainly used as a fodder or as a relief food in famine periods (Trickett 2006; Beaumont et al. 2013). In either case, consumed directly or indirectly, the unique isotopic signature of this plant should be observable in the post-medieval population. Sugar cane was already known in Europe and in Britain (see Chapter B.4.2.2) however it was not until the 1850 century that it became less expensive and thus available to the lower segments of the society (Mintz 1985: 148; Spencer 2011: 42).

5.1.4.2 Isotopic investigations of diet

Although the sample size is very small, the carbon and nitrogen isotopic values obtaned from the post-medieval cemetery of All Saints (York) are very similar to these from the latest part of the medieval period suggesting a terrestrial C_3 diet with a significant marine input (see Figure 114) (Müldner and Richards 2007b). Several reasons explain the continued consumption of fish in the post-Medieval York period. Firstly, at least during the Elizabethan period even the decrease of the Catholic Church's influence and the abandonement of the Lenten fast after the Reformation, the fasting periods and thus the consumption of fish in these days was encouraged to promote England's role as a seafaring nation (Fagan 2006: 188; Serjeantson and Woolgar 2006: 130; Spencer 2011: 99, 105). Secondly, the proximity of York to the coast, might explain why these resources were still popular. And lastly, in the wealthy households, while consuming less amount and variety of fish compared to previous periods, it seems this product was still considered an acceptable gift (Serjeantson and Woolgar 2006: 130; Müldner and Richards 2007b).

The individuals from the post-medieval cemetery in Wharram Percy possibly came from wealthy rural backgrounds and while it was expected that these people would have had a preference for imported sea-products or sugar cane, their isotope data show similar patterns as their poorer medieval ancestors. Also, the carbon isotope ratio suggests this input of marine resources and possibly of low-$\delta^{13}C$ freswater fish in the diet of this population (Mays 1997). (This data not added in the Figure 114 because only the carbon values were reported).



Graph by author. Data from: Trickett (2006), Müldner and Richards' (2007b) and Beaumont et al. (2013). Data represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 114: Average isotope values for the English post-medieval sites referred to in the text

Despite the documented difference in social and economic levels, the populations from Chelsea (London) and Coventry seem to have followed a predominantly C_3 diet (Figure 114). The elevated nitrogen levels combined with a terrestrial carbon signal suggests that both population relied on freshwater fish or omnivorous animals, such as pigs. However, the consistently higher nitrogen values in the individuals from Chelsea suggest that they consumed more meat or higher trophic level fish than the individuals from Coventry. This analysis was supported by the biographic study which revealed a link between higher nitrogen and known high social status. The isotope data does not suggest that the available C_4 plants (maize, millet and sugar cane) contributed significantly to the diet of these populations although it is still possible that maize was used as a fodder for terrestrial herbivores (Trickett 2006). Maize was also investigated as a potential relief food during the Great Irish Famine (1845-1852) by comparing the individuals buried in the Lukin Street Cemetery (London) in the period of the Famine against those found in the Kilkenny Union Workhouse cemetery (Rep. of Ireland) (Beaumont et al. 2013). The authors found that the average nitrogen value for the Kilkenny individuals was low compared to the individuals from Lukin Street in London who showed increased nitrogen values suggestive of a varied diet (Figure 114). All the individuals from Kilkenny showed below 12‰ nitrogen an while documentary sources suggest maize was imported between 1846 and 1847 as a famine relief food, only three adult individuals showed above -17‰ carbon values consistent with its consumption. Furthermore, as none of the individuals from Kilkenny show elevated nitrogen values suggestive of malnourishment, the authors suggested that due to the slow turnover rate adult bone, its collagen was possibly not sensitive enough to identify short shifts of diet (Beaumont et al. 2013: 94).

Finally, one of the main consequences of the Industrial Revolution was the increase in food mobility. Livestock as well as fish and even vegetables arrived to the urban markets not only from all over the country but also from Ireland and it was not uncommon for the animals to be moved around the country to be fattened (Spencer 2011: 248-249). In terms of analysing the isotope data, this movement should be taken into account thus obtaining a reliable, contemporaneous animal baseline would be paramount for the study of the post medieval diet through stable isotope analysis.

5.1.4.3 Summary

The post-medieval diet is dominated by cattle (reared for meat and milk), sheep/goat and pig. Mutton was the most esteemed livestock but the presence of pig in urban and rural sites increased as the period advanced. Fish, usually marine but also migratory species, was also an important part of the diet. Freshwater fish was most possibly limited to the wealthy households while stockfish and preserved fish would have been widely available and affordable. Cereals, pulses and vegetables remain widely available. The appearance of city markets and the improvement of transport improved food mobility towards the cities however the significant crowding of the industrial centres results in a widespread malnutrition.

A major shake-up of the traditional English diet occurred after the return Columbus from the Americas when the new range of products arrived to Europe and to the British Isles became incorporated into the diet. The most notable inclusions were potatoes, maize and sugar cane, the last two being C_4 plants. Maize was mainly used as a fodder or as a relief food in famine periods and sugar cane became widely available after 1850 when it became cheaper and thus affordable to all levels of society.

5.2 Dietary characteristics and isotope analysis through time in Catalonia

Catalonia is located at the north-east corner of the Iberian Peninsula, bordering with France across the Pyrenees in the north and with the Mediterranean Sea in the east. Unlike the vast amount of data available for the study of the diet in the British Isles, the data available for Catalonia is much more limited therefore data from other parts of the Mediterranean basin will be carefully considered.

5.2.1 Romano Catalan diet

Most of the dietary information during the Roman period comes from ancient texts describing the culinary customs of the wealthier classes of the society in Italy or the eastern Mediterranean area (see Purcell 2003; Wilkins 2003). The use of these recipe and medicine books to infer the diet should be done cautiously since it appears that the local provincial population mixed the newly imported Roman habits with their former traditional way of life (King 2001; Cool 2006)

5.2.1.1 Archaeological data and documentary sources

It is well accepted that the Roman diet was centred on the Mediterranean triad of cereals, olive oil and wine with the addition of legumes, mainly broad beans, lentils, chickpeas and peas (Gómez i Pallarès 1996; Garnsey 1999: 13; Ejstrud 2006). Wheat and barley, associated with high and low status respectively, were the most common cereals (Gómez i Pallarès 1996). Millet, a C_4 plant, is known to have been harvested and consumed in Eastern and Southern Europe including the region of Catalonia since the 2nd millennium BC (Alonso Martínez 2000; Tafuri et al. 2009; López-Costas and Müldner 2016). It is worth noting that other C_4 plants, such as the *Spartina* sp. present in the area, could have also been eaten by herbivores diet, entering the food chain (López-Costas and Müldner 2016). Finally the Roman population ate a wide variety of vegetables, mainly onions but also turnip, radishes, carrots, broccoli, cabbage, leek and cucumber among others, and fruits such as apple, fig, pear, prune, pomegranate, grapes, quince and blackberries. Dried fruits such as chestnuts, walnuts, almonds and imported Asian hazelnuts and Syrian pistachio were also consumed (Gómez i Pallarès 1996).

The zooarchaeological data collated by King (2001) indicated that during the Spanish Roman period the population's dependence on pig increases adopting a more 'Roman' diet (i.e. high pig, low cattle and sheep) throughout the Roman period before decreasing in the Late Roman period. However the local preference for cattle or sheep/goat is also observable and regional patterns exists across the peninsula and the western Mediterranean area (King 1999; Genera i Monells et al. 2010; Colominas 2017). For example in Gallia Narbonensis (SE France, north from modern Catalonia), Roman urban and rural sites show a very high percentage of goat/sheep remains; possibly the remains of the Greek influence established in the area during the 1st millennia BC. Similarly, pre-Roman Catalan, Provençal (SE France) and Valencian (West Mediterranean coast) sites are dominated by sheep and goat (King 2001; Iborra Eres et al. 2010). Nevertheless, increase in the presence of pig was detected when comparing the faunal assemblages of the Iron Age Iberian and the Early Roman period (Colominas 2017). A similar pattern was observed in Empúries (Figure 115) where pig was found more abundantly than sheep and goat; 54-58% and 23-32% respectively (Estévez 1987: in King (1999)). It seems that in this region, the 'Roman' pattern dominated by pig bones is mainly found in Roman colonies or sites with little Greek influence. Documentary sources also suggest that pork meat was a cornerstone in the Mediterranean diet and probably also in Roman Catalonia while beef was the cheapest meat and thus widely affordable (Gómez i Pallarès 1996). Chickens, hens and their eggs were also an important source of meat and protein. Game hunting was a common activity from all, high and low status households, and one of the most favoured wild animals was wild boar although hare was also very well appreciated. Cheese from sheep and goats milk, was the only dairy product widely available and popular as the preservation of milk, butter and cream was problematic (Faas 2006). It is worth noting that nor meat neither fish were considered a staple foods but more of a supplement to the diet even though there seems to be an increase in the meat consumption in Italy during the early Empire (Craig et al. 2009).

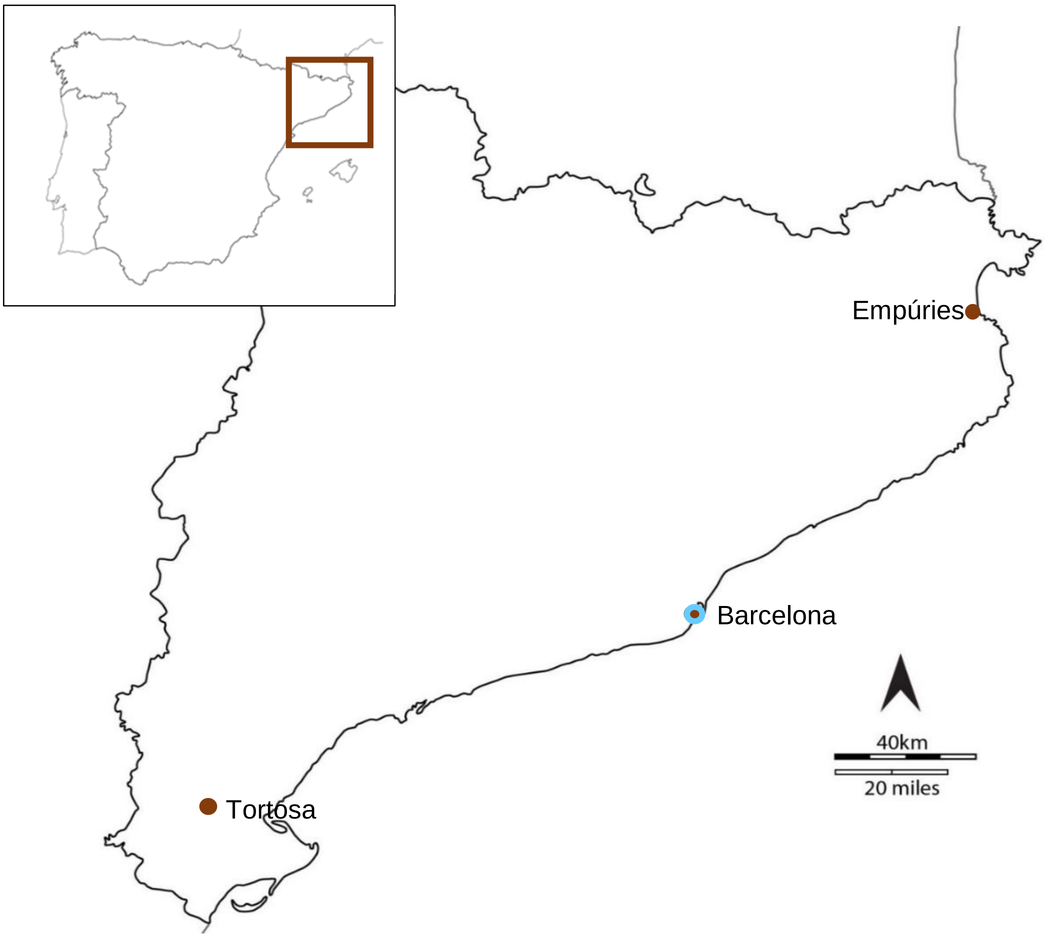


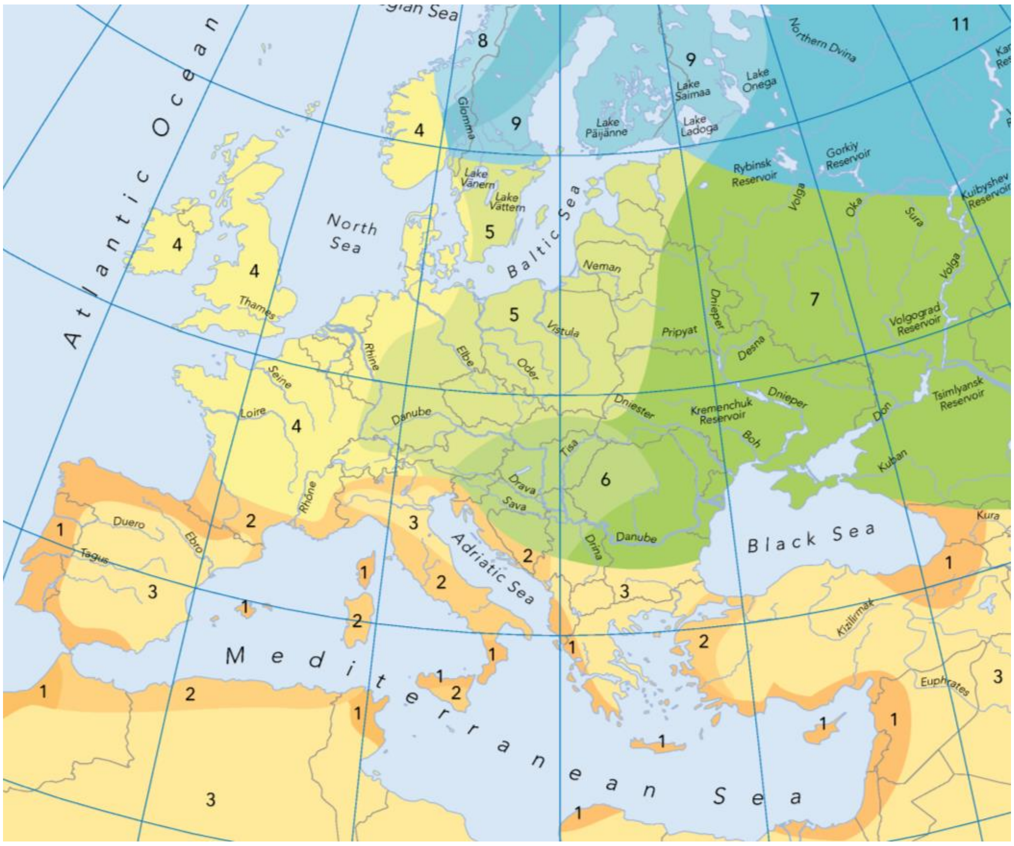
Figure 115: Location of the Catalan Roman sites mentioned in this section

Legend: ● Faunal assemblages; ○ Stable isotope data

The status of fish is complex and ambiguous since it was considered to be for the poor and a sign of destitution, however it seems that marine species and seafood were considered a sign of luxury by the elite. Nevertheless the appearance of fish in the art, the detailed description of the different fishes available and the plethora of recipes that have survived suggest that, at least from the 2nd century BC, eating fish was very common. While freshwater fish was consumed, most of the available fish and seafood was from marine sources. It seems that fish consumption was also higher in coastal sites (Gómez i Pallarès 1996; Prowse et al. 2004; Prowse et al. 2005). The coastal colonies from Hispania were well-known for the production and distribution of *garum* (cooking fish sauce) but similarly to what it was seen in the Romano-British diet (section B.4.1.1) the impact of this food in the overall diet of the wider population was possibly limited (Garnsey 1999). Interestingly, in a Flavian *domus* (residence of the Roman elite) in the coastal site of Destrosa (modern Tortosa, Figure 115), from the typology of the amphorae recovered, the archaeologists suggested the inhabitants consumed *garum* and wine (Genera i Monells et al. 2010).

5.2.1.2 Isotopic investigations of diet

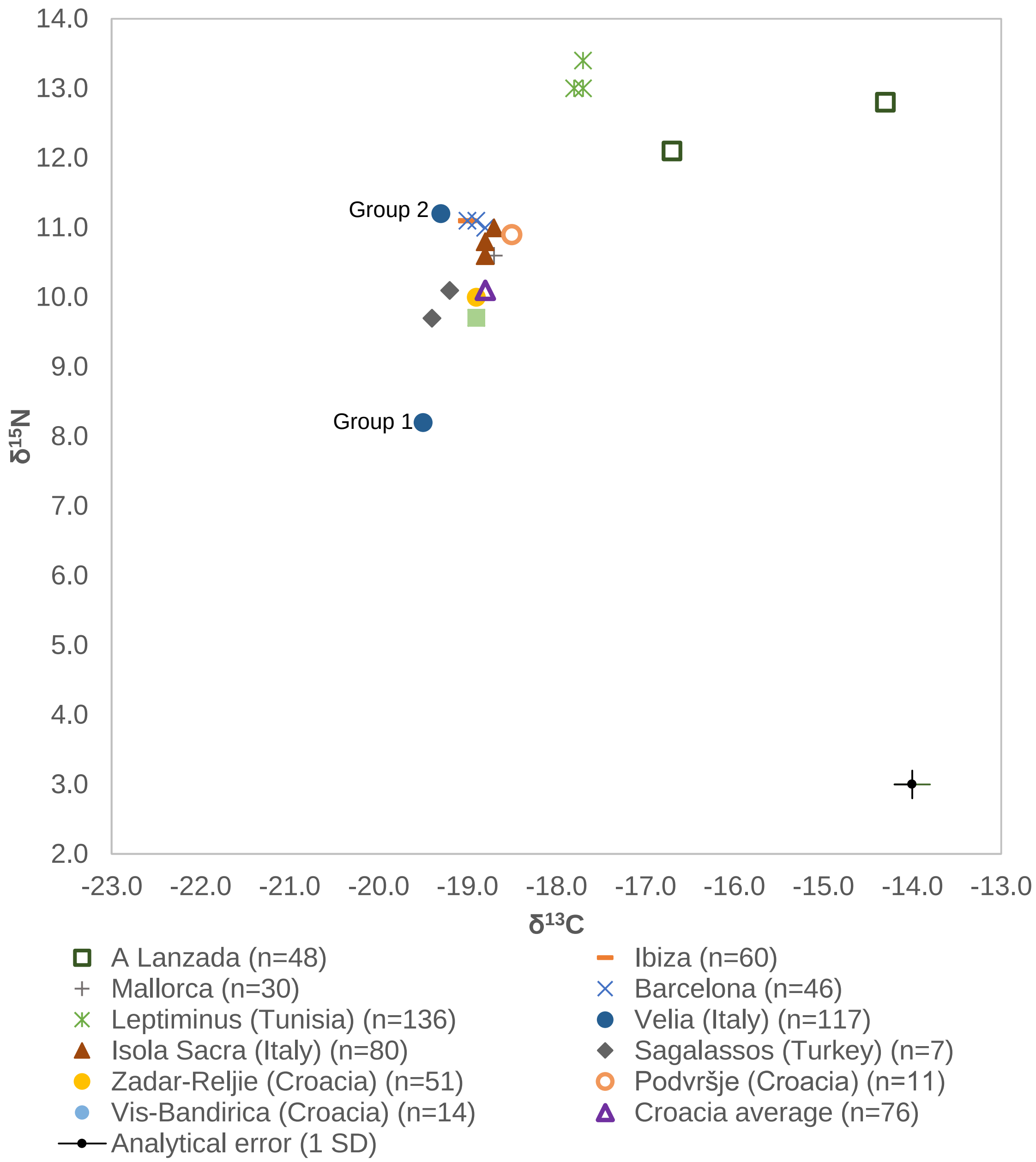
Catalonia has a Mediterranean climate like most of the coast of the Mediterranean basin including southern France, Italy, the Dalmatian coast, the west coasts of modern Greece and Turkey and part of the north-African coast (Figure 116). This peculiarity needs to be taken into account when selecting sites to compare the data obtained from the Roman site of Santa Caterina. Barcelona has a more temperate and humid climate than the South and Central Spain while being drier and warmer than the regions located at the Atlantic coast of the Iberian Peninsula. For this reason, the limited isotope data from Catalan sites has been supplemented with sites located in the south of France and Italy, and with the climate variations in mind, from Spain.



Key: *Subtropical climates*: 1: maritime; 2: intermediate; 3: continental.
Temperate climates: 4: maritime; 5: transitional; 6: intermediate; 7: continental.

Figure 116: Climate map of Europe (Carthographied by GRID-Warsaw)

The isotope data obtained from the site of Carrer Ample 1 (Barcelona) suggest that diet was possibly dominated by terrestrial C_3 plants with the addition of some meat (Rissech et al. 2016). The higher nitrogen values were suggested to be most probably related to the consumption of pork, two of which showed $\delta^{15}N$ values of 7.3 and 8.7‰, than to the consumption of marine resources. While, given the supposed low socioeconomic status, this was not considered to be an unexpected result, the authors also noted that the consumption of estuarine fish could also explain the low $\delta^{13}C$ and high $\delta^{15}N$ values (Figure 117). The very high prevalence of carious lesions in this population was also considered to be indicative of a carbohydrate-rich marine-protein-low diet (Rissech et al. 2016).



Graph by author. Data from: García et al. (2004), Prowse et al. (2004, 2005), Craig et al. (2009), Keenleyside et al. (2009), Fuller et al. (2010, 2012), Lightfoot et al. (2012), López-Costas and Müldner (2016) and Rissech et al. (2016). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 117: Average isotope values for Roman Mediterranean sites referred to in this section

Stable isotope values from late Antiquity to Early Byzantine (4th – 6th century AD) human and animal remains from an urban cemetery in the Pityusa Island of Ibiza are very similar suggesting that this population followed that of Velia with a primarily terrestrial diet (Nehlich et al. 2012). Similarly, the carbon and nitrogen isotope values for the same population suggest a terrestrial C_3-based diet possibly based on bread, legumes, vegetables, cheese and meat, with a possible little input of marine or C_4 dietary sources (Fuller et al. 2010). The carbon, nitrogen and sulfur isotope analysis of the 39 individuals from a Late Roman site in Mallorca also suggested that the population followed a based on a C_3 terrestrial and animal diet. In this sample, males show higher carbon values compared to females (Garcia et al. 2004).

The data obtained from the Roman and post-Roman (Germanic) human remains from the north west area of Spain of A Lanzada, dated from the 100 to the 700 AD (Figures 117 and 118) showed a temporal shift between periods for both $\delta^{13}C$ from -16.7‰ to -14.3‰ and for $\delta^{15}N$ from -12.1‰ to -12.8‰ (Figure 117). These results suggest that the post-Roman population might have included a higher proportion of marine and/or of C_4 plant (probably millet) in the diet (López-Costas and Müldner 2016). The authors note that carbon and nitrogen ratios vary more significantly within than between periods, which could mean that the individuals of the same population followed significantly different diets (López-Costas and Müldner 2016).

Figure 118: Spanish and Mediterranean Roman sites referred in the text

Legend: Stable isotope data

GVL: Gumaca Vela Luka, Croatia.

Elsewhere in the Mediterranean basin, isotope data has been obtained from the Imperial coastal site of Velia (Italy, 1^{st} to 2^{nd} century AD) suggest that the majority of the population (Group 1) followed a high cereal consumption with a variable input of meat or dairy and a minor consumption of fish/*garum*. The individuals from Group 2, that show higher nitrogen values, consumed more meat and high trophic level fish (Craig et al. 2009) (Figure 117 and 118). Similar results were found for the Imperial population of Isola Sacra and Portus Romae (nearby Rome, Figure 118) where while the overall diet seemed to have been based on terrestrial C_3 resources, the higher nitrogen values suggest the input of marine fish from a medium to high trophic level (e.g. turbot, bass, cod/hake, moray eel, sole and dolphin fish). Further analysis on this population showed that females have consistently low $\delta^{13}C$ and $\delta^{15}N$ values compared to the males, possibly suggesting that, in general, they consumed less marine resources (Prowse et al. 2004; Prowse et al. 2005).

On the Mediterranean coast of Africa, isotope analysis on the Roman and Late Roman population of Leptiminus, Tunisia have revealed that, like in the sites at the northern Mediterranean coast, the diet was dominated by terrestrial C_3 plants with significant input of marine fish (Figures 117 and 118). The authors also suggested that the isotopic signature for *garum* was not strong enough to enrich the carbon and nitrogen ratios in this significant manner, a shift better explained by the consumption of high trophic level fish (Prowse et al. 2004, Keenleyside et al. 2009). Interestingly, unlike in the previous case, no significant differences were found between males and females. This could be because both sexes were following the same diet or that the existent dietary variation was not reflected in the isotopic signature (Keenleyside et al. 2009).

Roman population from the Croatia (Zadar-Relje, Podvršje and Gumaca Vela Luka, Figure 118) followed a C_3 terrestrial-based diet however the significant human-fauna offset in the carbon and nitrogen isotopes observed in this sample suggest that the diet in this population was supplemented with marine resources (Lightfoot et al. 2012). The human remains from the Late Imperial period (300 – 450 AD) from the Turkish site of Sagalassos (Figure 118) suggest that they were also following a terrestrial C_3 diet. The higher nitrogen ratios observed in this sample were probably associated to a heavy reliance on pork whose also higher nitrogen levels suggest they were fed on human refuse (Fuller et al. 2012).

5.2.1.3 Summary

Documentary sources and archaeological and isotope data suggest that the Roman Catalan diet was centred on the Roman triad (cereals, olive oil and wine) supplemented with legumes. Following Roman trends, pig was possibly the preferred meat although local patterns with high cattle and sheep/goat can be found. Overall, with the exception of the Tunisian site of Leptiminus and the Galician site of A Lanzada, the average isotopic ratios of all the sites around the Mediterranean basin are comparable. If these two sites are not considered, the isotope data does not suggest that neither fish nor fish sauces had a significant input in the Roman diet. Finally, the direct or indirect consumption of C_4 plants should be taken into account when interpreting the isotope data from this region.

5.2.2 Early medieval Catalan diet

The Early Middle Ages are marked historically by the arrival of the Eastern European Visigoths at the Iberian Peninsula and by a greater climate instability. The first half of the period is characterised by cooler temperatures and wetter conditions until the mid-sixth century followed by drier conditions in north western Europe. From mid-seventh to the mid-ninth centuries, there seems to be a shift to warmer temperatures but this period saw the harshest winters on record. These climatic conditions possibly affected the agriculture, the crop management and the farming strategies of the early medieval populations. From the late seventh century onwards, new centres of trading and kingdoms emerge in England, France and Italy (McCormick et al. 2012). From a historical context perspective, similarly to what was observed in Western Europe, the Catalan Early

Middle Age is characterised by the return to the rural lifestyle, with a decrease in trade (Fàbrega 2016: 19). However far from the oversimplification of the rural economy, recent studies suggest it reorganized and became more diverse and thus possibly resistant to food shortages (Henning 2009; Rottoli 2014; García-Collado 2016).

In this section as well as in the following ones, only data regarding Christian populations will be reported because the aim of this section is to investigate the specific diet that the studied populations could have followed. It is not the aim of this project to give an exhaustive overview of the diet of all contemporary communities inhabiting the Iberian Peninsula, such as the Jewish and the Muslim populations which are known to have followed different diets communities (Fuller et al. 2010; Mundee 2010b; Alexander et al. 2015; Contreras Mas 2017). Finally, only the southern region of Europe has been used to inform this chapter because the agricultural traditions derived from the interpretation of the archaeological record are known to have been different from northern and east Europe (Ruas 2005; Quirós Castillo 2014).

5.2.3.1 Archaeological data and documentary sources

Documentary sources suggest that the Carolingian Catalan population was a meat eater one, although the type of meat and the preparation method changed depended on wealth of the household (Fàbrega 2016: 46). This cuisine is also thought to be traditionally closer to the classic cuisine than to the late medieval cuisine (Salamon et al. 2008; Contreras Mas 2017: 44). It is worth noting that, in general, there is a significant lack of bioarchaeological published data from the early medieval population in Catalonia and Spain. For example, it appears that by the fifth and sixth centuries, the new Christian influence in western Europe encouraged the consumption of fish in fasting days (Hoffmann 2005), however no published research investigating this aspect of the diet was found. This will seriously limit any comparative analysis between sites and time periods and will prevent the drawing of a comprehensive idea of the type of diet followed by the studied populations (Mundee 2010b; Vigil-Escalera Guirado et al. 2014).

Archaeobotanical studies in the city of Lleida (Figure 119) indicate that from the Roman to the Islamic period (eighth to 12th centuries in Lleida), the most abundant cereals were wheats, oat and rye, whose consumption during the Early Middle Ages in Europe increased coinciding with the expansion of the cities. Rye, as a crop, is extremely resistant to cold, it grows well in poor quality soil and can be used as a fodder; qualities which possibly made it a desirable cultivar (Alonso Martinez 2005).

Figure 119: Location of the early medieval Spanish sites mentioned in this section

Legend: ● Faunal assemblages; ○ Stable isotope data

An archaeobotanical study carried out in Mediterranean coastal France, suggested that the most common crop in the local fields were wheat and oats. The assemblage has also produced a significant amount of pulses (lentils, fava beans and pea) and, though not recovered, it is known that chickpea was also available (Ruas 2005). A similar study from the Visigothic (sixth to eighth centuries AD) rural site of Gózquez (Madrid, Figure 119) revealed a probable predominance of hulled barley, possibly used to feed livestock, followed by free-threshing wheats (e.g. bread wheat). Oat and rye cereals, legumes and wild fruits are poorly represented (Vigil-Escalera Guirado et al. 2014). It is possible that this difference is related to the climatic variation; if this is the case, it would be expected the Catalan sites studied in this project would resemble more, in their agricultural tradition, to the Southern France sites.

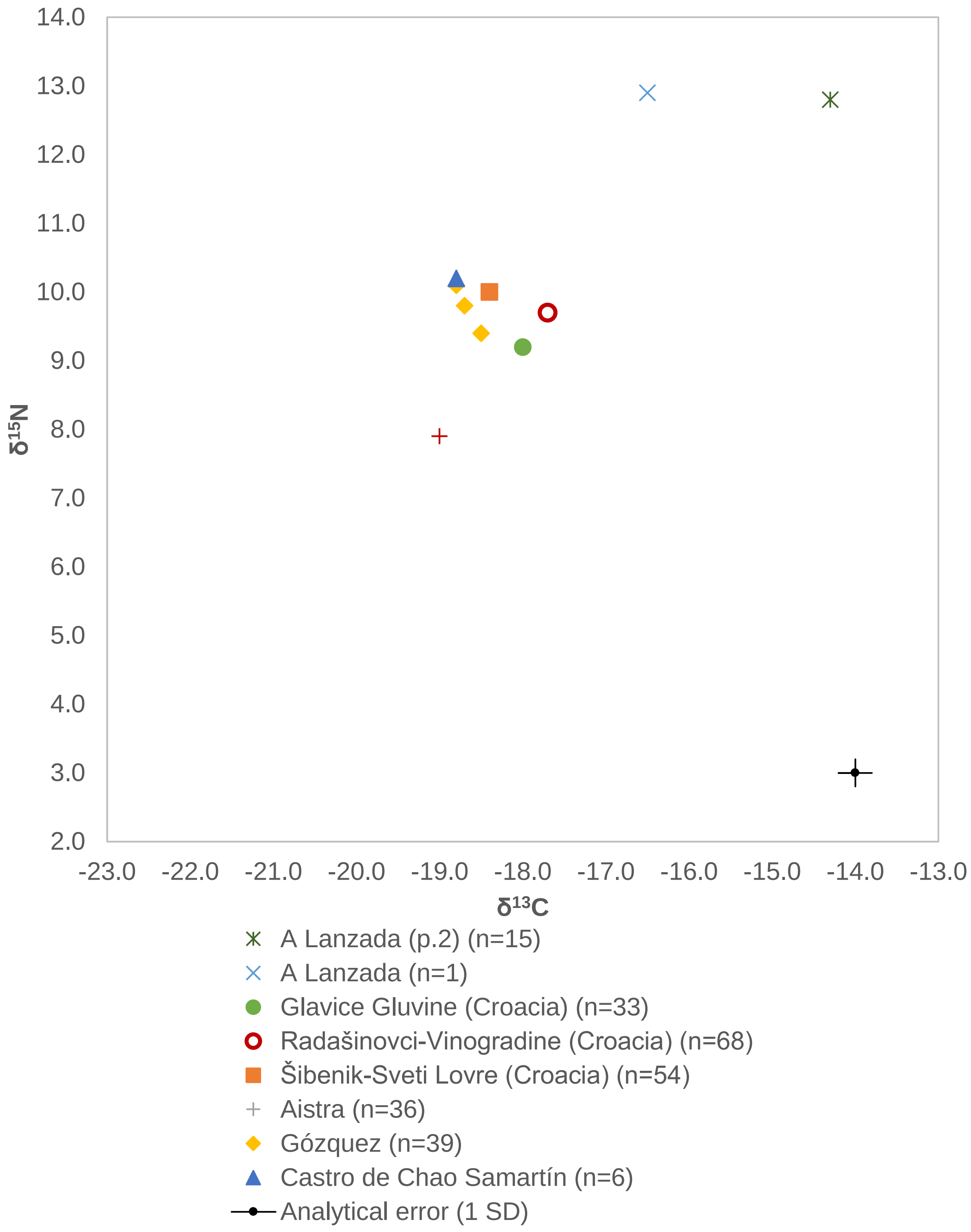
The zooarchaeological records from Gózquez is dominated by domestic mammals with few remains of game (red deer and hare). By weight, cattle and horse seem to have been more important than sheep/goat. When the first phase of the site (sixth to seventh centuries) is compared to the second one (seventh to eighth centuries) the presence of sheep/goat remains doubles while there is a decrease in the presence of cattle and horse remains which the authors suggest could be related to a change in the disposal practices. Nevertheless, in both periods, pig remains are very scarce, demonstrating the limited role in this regional economy (Vigil-Escalera Guirado et al. 2014). In contrast, the faunal assemblage from the northern Spanish early medieval rural sites of Aistra, Zornoztegi, Zaballa and Dulantzi (Figure 119) indicate that domesticates, mainly cattle, goat/sheep and pig, dominated. Sheep/goat followed by cattle remains dominate in most of the sites, with the slaughtering pattern suggesting that the main purpose of this domesticate was the production of secondary products (wool, milk, manure and traction). Zornoztegi is the only site where cattle dominates and only in the high status site with archaeologically evident social differentiation of Aistra, the proportion of pig remains is significant (Sirignano et al. 2014). As seen in other periods, the status if the pig is confusing at best. While documentary sources seem to suggest that with the arrival of the Germanic tribes, the importance of pig husbandry should have increased, an extensive zooarchaeological survey on the pig husbandry in Spain revealed that the stocks decreased from the Roman to the early Middle Ages (Morales Muñiz 1992). This would be in accord with the idea that only the people who could afford to rear pigs, actually consumed it, suggesting that the consumption of pig was a symbol of high status.

Archaeobotanical and archaeozoological data in the northern Italian early Middle Ages suggest that a broad spectrum of vegetables (cultivated and wild) as well as animals were present. As in the Roman period, barley and wheats seem to have been the most commonly cultivated cereals although an increase in the presence of rye is also noted (Rottoli 2014). Similarly, during the early medieval period (500-1000 AD) the population of southern Italy consumed a terrestrial diet based on cereal grains, legumes, fruit and vegetables with a small supplement of meat and secondary products (Montanari 1988: cited in Salamon 2008).

5.2.2.2 Isotopic investigations of diet

There are very few stable isotope studies investigating diet in Spain and around the Mediterranean that could inform the dietary characteristics of the early medieval Catalan population. The isotopic signature of faunal remains from Aistra, Zornoztegi, Zaballa and Dulantzi suggest that sheep/goat, cattle and pigs were consuming C_3 plants with some variation in the nitrogen isotope due to the different husbandry strategies. In contrast, it seems the domestic fowl was fed on C_4 seeds, perhaps millet (Sirignano et al. 2014). Compared to these results, sheep/goat and pig remains from Gózquez show high nitrogen values, possibly related to the sampling of young individuals. However the authors suggested that the consumption of manured plants was the most probable explanation for the high nitrogen values in cattle and horses (García-Collado 2016). The isotope data obtained from the human remains from Gózquez (Figure 120) suggest that this was a homogeneous community with limited internal differences. This community followed an omnivorous terrestrial diet dominated by C_3 with small input of C_4 plants, consumed as a grain or fed as a fodder to the animals, and supplemented their diet with animal protein. Neither isotopic data nor archaeological record suggest the consumption of freswater or marine fish (García-Collado 2016).

The seven adult individuals from the site of Castro de Chao Samartín (Astúrias; sixth to 15th centuries) suggest that these individuals followed a C_3-based diet supplemented with terrestrial animal protein and possibly freshwater fish from the resources (MacKinnon 2015: 131). Interestingly, the other northern early medieval rural site of Aistra (n= 35) produced an isotopic signature suggestive of an omnivorous diet which would have included C_4 plants as well as freshwater fish (Quirós Castillo 2013: 26-27). The author argued that the wide variability in nitrogen and carbon values observed in the sample (range of $\delta^{13}C$: 5.3‰; range of $\delta^{15}N$: 3.8‰) suggested that the population had a varied diet which would have helped them overcome food crisis (Quirós Castillo 2013: 29). The post-Roman (fifth to seventh centuries) population from A Lanzada (n=20) and the medieval individual analysed seem to have relied on marine resources and C_4-plants more heavily than their Roman predecessors (López-Costas and Müldner 2016) and other contemporary Spanish communities (Figure 120).



Graph by author. Data from: Lightfoot et al. (2012), Quirós del Castillo (2013), MacKinnon (2015), García-Collado (2016) and López-Costas and Müldner (2016). **D**ata represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 120: Average isotope values for the early medieval Mediterranean sites referred to in the text

In the Early Medieval Croatia, carbon and nitrogen isotope values still reflect a C_3-based terrestrial diet (Figure 120). However, while the offset between human and faunal carbon isotope values falls within the normal range of 0-2‰, that of nitrogen is significantly higher than 2‰, suggesting that the primarily terrestrial diet was supplemented with C_4 elements, probably millet, or low trophic level marine protein (Lightfoot et al. 2012). Nevertheless the marine source identified in this sites during the Roman period seems to disappear, or at least be so much reduced as to not be identified isotopically (Lightfoot et al. 2012).

5.2.2.3 Summary

Documentary sources as well as archaeological and isotope data suggest that the early medieval diet around the Mediterranean area was dominated by C_3-plants and terrestrial animal protein, supplemented by vegetable and pulses and a small direct or indirect input of C_4 plants. Terrestrial meat was possibly obtained primarily from herbivores, mainly sheep/goat and cattle with pig possibly only present in the high status households. By the fifth and sixth centuries, the consumption of fish in fasting days was encouraged by the new Christian and while some isotope data might suggest the consumption of this resource, the paper of fish in the early medieval diet has been scarcely investigated.

5.2.3 Late medieval Catalan diet

As in the Anglo-Saxon and the English late medieval periods, the ecclesiastic calendar had a very strong influence on the diet Catalonia and Spain. In medieval Catalonia, there were 150 fasting days in which only one big meal was allowed although nibbling was acceptable (Thibaut i Comalada 2006: 37-38). As during Lent and on “fish days”, meat and fats were not allowed; the traditional Mediterranean staples of oil, wine, wheat and fish in combination with legumes, nuts, vegetables, and cheese and milk made up the late medieval diet for fasting days (Maranges 2006: 45; Thibaut i Comalada 2006: 38-41). The Arab influence on the diet in the entire Peninsula cannot be underestimated. Even in the northeast region of the Iberian Peninsula which was under Arab occupation for less than a century, its influence is still noticeable as two of the most important products they introduced were rice and sugar cane (Thibaut i Comalada 2006: 64-65).

It is worth noting that this time period can be divided into two. From the turn of the millennium until the 13th century, the territorial consolidation and the production of surplus allowed the birth of farmer markets which allowed the population to be more resistant to food crises. However in the 13th and 14th centuries, almost all the agricultural production turned to cereals; the failure of this crop is one of the principal causes of starvation and mortality during this period (Bertrán Roigé 1990: 36).

5.2.3.1 Archaeological data and documentary sources

Most of the research on medieval Catalan Cuisine are based on two books, *El Llibre de Sent Soví* (1324) and *El Llibre de Coch* (pre-1491) (Maranges 2006: 14). According to these books, the most important element in the diet was cereal, and more specifically, bread. Wheat was considered to be the best of the cereals but it was probably only available to the wealthiest; barley and millet were used to make a poor quality bread available to most of the population (Bertrán Roigé 1999; Maranges 2006: 249-250). Millet and sorghum (C_4 plants) seem to have been mainly consumed by the lowest classes and the Muslim population (Alexander et al. 2015). Meat was considered essential for human subsistence thus was probably available that all levels of society (Maranges 2006: 55). According to these books, goat was the most common meat and kid, hen and chicken were highly esteemed. Cattle was not well appreciated although calf meat was well considered but not widely consumed. In contrast, pigs had a very bad reputation and possibly was not a primary source of meat, nevertheless its meat was possibly the most available for the lower classes (Maranges 2006: 57; Fàbrega 2016: 30). Milk was well-loved but not widely available, sheep and goat milk was preferred to cow's, which was mostly used to make cheese; a cheap, staple food available to and consumed by all the population (Maranges 2006: 238-240; Thibaut i Comalada 2006: 69-70). Interestingly, some resources suggest that eggs were only allowed on "meat days" and were available to levels of society (Maranges 2006: 228; Contreras Mas 2017: 80) while other sources suggest that they were, along with cheese, a meat substitute on fasting days (Bertrán Roigé 2013: 53).

Fish and seafood were cornerstones of the regional cuisine and they mostly came from the Medietarranean area, there are few mentions of salted and dried fish (e.g. sardine, tuna and congre) and very few references to freshwater fish (Maranges 2006: 157-159; Fàbrega 2016: 30; Contreras Mas 2017: 69). River fishing was included in the seignorial rights, thus theoretically not allowed to the commoners, however, as it was easy to exploit, it may have been a significant food resource for the inland rural populations (Bertrán Roigé 1990; Thibaut i Comalada 2006: 70-71). Pulses (mainly beans, lentils and chickpeas), honey or sugar and a very wide variety of vegetables, available to everyone but more important for the poorer classes, were also part of the diet (Maranges 2006: 272).

The sources disagree in the use of fats in Catalan cuisine. Some sources suggest that fats were widely used (Maranges 2006: 57, 339-341; Thibaut i Comalada 2006: 66; Fàbrega 2016) while others suggest that, in most of the preparations, fat was not included (Contreras Mas 2017: 46). Nevertheless, if used, bacon and olive oil, used for different types of dishes, were the most common fats; less commonly used were walnut oil and butter (Thibaut i Comalada 2006: 66; Fàbrega 2016: 31).

Figure 121: Location of the Spanish late medieval sites mentioned in this section

Legend: ● Faunal assemblages; ○ Stable isotope data

CO: Cathedral of Oviedo; SML: San Miguel de Lillo; SJV: San Julián de Viñón; SPN: San Pedro de Nora; SPP: San Pedro de Plecín.

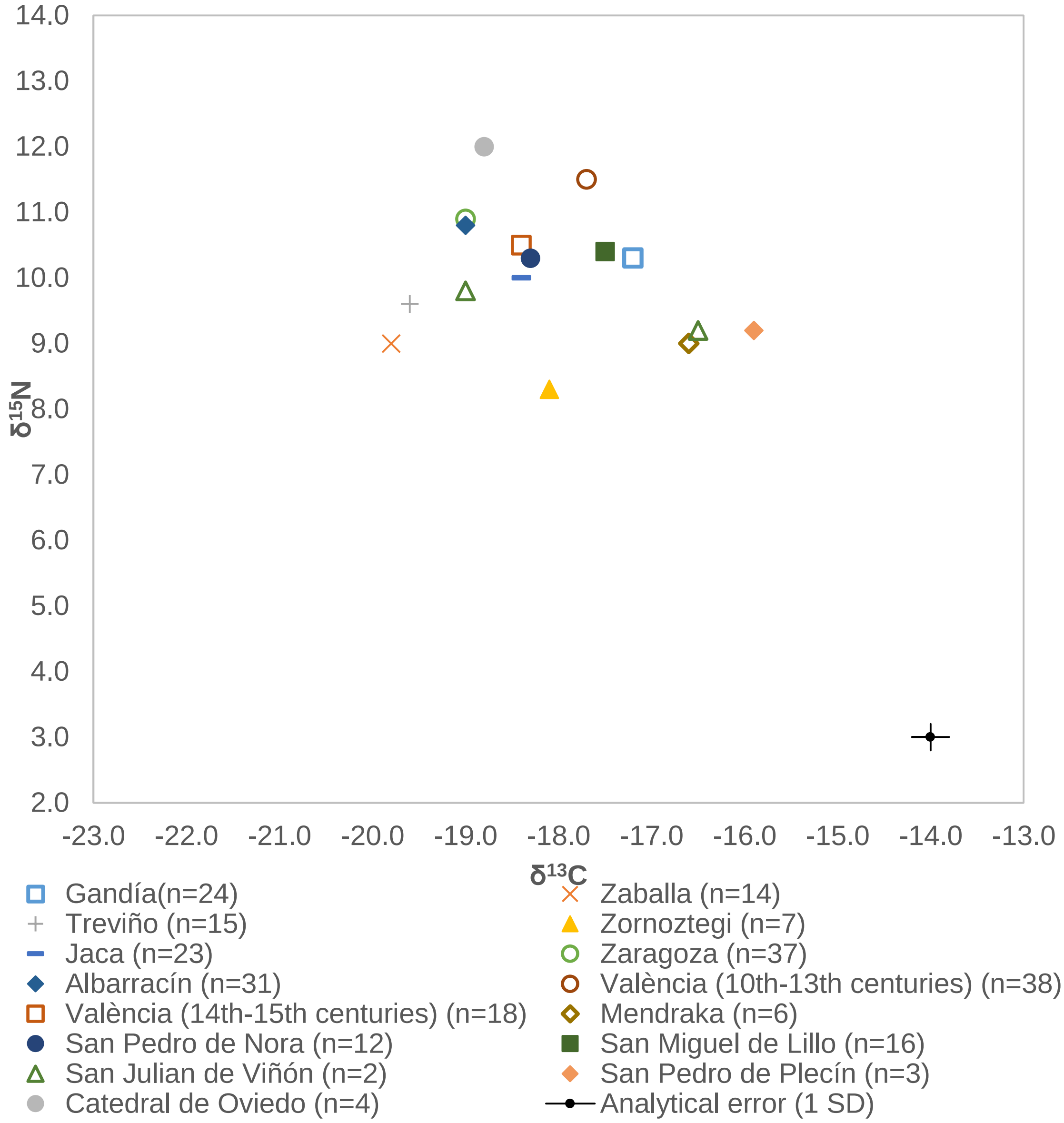
The wealthy tables were characterised by the number of dishes, the wide variety of meats, by the use of sugar and of quality wines. The diet of most of the population was based on wholemeal wheat or barley bread, the use of garlic and of onions, bacon was not an uncommon element in their diet and sometimes game (mainly pigeons and rabbits) was also added (Thibaut i Comalada 2006: 38). The amount and quality of meat included in the meals differentiated the middle from the lower classes in Catalonia as well as in the Balearic Island of Mallorca (Figure 121) (Thibaut i Comalada 2006: 59; Contreras Mas 2017: 45). Finally, food for some of the poorest of society was provided by some church and monastic communities. Accounting books from different alms houses indicate that ordinary poor received daily rations of bread and wine and most days, they ate meat, usually goat, but also cattle or pork (this last only in Lleida). Vegetables and legumes (fava beans, peas, chickpeas and lentils) were abundantly provided. Fish, fresh or salted, was sometimes served on fasting days. Eggs and cheese appear to be considered a supplement of the diet mainly for the fasting days (Bertrán Roigé 1999; Bertrán Roigé 2013).

Documentary sources and archaeological data therefore suggest that the late medieval Catalan diet was dominated by C_3 plants with a possible variable input of C_4 plants. Fish and seafood seem to have been moderately consumed and, when allowed, meat was available for all members of the society.

5.2.3.2 Isotopic investigations of diet

Carbon and nitrogen isotope analysis was carried out in 24 Christian individuals from the late Medieval Spanish (13^{th} – 16^{th} centuries) site of Gandía, located in the Mediterranean coast of the Iberian Peninsula (Figure 121). The 2‰ and 5.4‰ increase in carbon and nitrogen isotope values respectively, between herbivores and human suggest that this population consumed high $\delta^{15}N$ products such as poultry, eggs, pork or marine fish (Figure 122). The presence of a possible C_4 signature could be indicative of social segregation between Muslims and Christians where the former consumed primarily millet and sorghum and the latter, wheat (Alexander et al. 2015).

Two different studies reported on four different sites from the northern Spanish region of the Basque country (Lubritto et al. 2013; Quirós Castillo 2013). While all the populations seem to have followed a terrestrial C_3 plant diet with variable consumption of meat and a scarce input of freshwater fish, there are significant differences between sites. Treviño and Zaballa show slightly higher nitrogen and lower carbon levels compared to Aistra and Zornoztegi (Figures 121 and 122). The authors suggested that the two former populations possibly had a higher input of meat resources in their diet while the two later populations followed a more omnivorous with a higher input of C_4 plants, possibly millet. The interpretation of this data possibly reflects the type of society living in each village; Aistra and Zornoztegi were rural villages, Treviño was associated to a castle and Zaballa was associated to the wealthy aristocracy. These results support the hypothesis that from the 11^{th} century onwards, the consumption in meat increased in the wealthy households. Nevertheless the wide range of carbon and nitrogen values per each site, suggest that all populations had a very varied diet which possibly reduced the chances of malnutrition in periods of crisis (Lubritto et al. 2013; Quirós Castillo 2013).



Graph by author. Data from: Mundee (2010a in: Quirós del Castillo (2013), 2010b), Lubritto et al. (2013), Quirós del Castillo (2013), Alexander et al. (2015) and MacKinnon (2015). Data represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 122: Isotope signature for the Spanish sites referred in the text

The results from the five late medieval sites from the region of Asturias (Cathedral of Oviedo, San Julián de Viñón, San Miguel de Lillo, San Pedro de Nora and San Pedro de Plecín, Figure 121) show some dietary differences between their populations. For example, it was argued that the data obtained from San Pedro de Nora suggested that its inhabitants consumed freshwater resources (e.g. catfish and eel) from the Nora River (MacKinnon 2015: 138) (Figure 122). The author argued that the two individuals (one male and one female) from the cemetery of San Juan de Viñón suggest that they followed significantly different diet. The male seems to have had a terrestrial C_3-plants based diet while the female shows a stronger C_4-plants signature. Similarly, the three individuals from San Pedro de Plecín possibly relied on C_4-plants consumed directly or indirectly. Finally the isotopic signature of the individuals (n=4) from the Cathedral of Oviedo suggest that their diet was based on C_3-plants supplemented with high trophic terrestrial protein (pig, suckling pig or kid goat) or freshwater fish; all of them considered of high status (Figure 122). MacKinnon (2015: 160) argued that while some individuals might have consumed freshwater resources, marine resources and C_4-plants possibly did not contribute significantly to their diet.

The population from the late medieval population from Jaca (Aragon, Spain, Figures 121) shows significantly high nitrogen values suggesting the dietary protein was from animal sources (Figure 122). However the wide range of nitrogen values combined with terrestrial carbon values could also indicate that this population consumed freshwater fish in varying amounts. Some individuals in this site show significantly higher carbon values, possibly related to the consumption of C_4 plants and the author hypothesised these could have been migrants (Mundee 2010b). Other populations from the urban or semi urban sites from València and Aragon (e.g. Albarracín and Zaragoza) also showed the characteristic C_3 terrestrial diet, although there seems to have been a more significant input of marine resources as well as of C_4 plants (Figure 122). The variation of carbon and nitrogen signatures also suggest that a wide variety of food products were available in the urban centres (Mundee 2010a: in Quirós Castillo 2013).

Legend: Stable isotope data

Figure 123: Mediterranean late medieval sites referred in the text

Elsewhere in the Mediterranean basin, the isotope results obtained from a 15th century population from Rome showed a significant shift in nitrogen and carbon values compared to the sixth century population of Castro dei Volsci (Figures 122 and 123). The authors considered that the high nitrogen values observed in the later population is indicative of an increase in the reliance on fish, possibly coming from the North Atlantic region (Salamon et al. 2008). Documentary sources indicate that from the 14th century, Atlantic marine resources flooded Italy. Here again the authors noted the great variability on the nitrogen values and suggested that, perhaps, these could reflect socio-economic status and/or relative religiosity (Salamon et al. 2008). Finally, the isotope data from late medieval Greek site of Kastella (Heraklion, Crete, Figure 123) suggest that, in general, the diet was based on C_3 plants and terrestrial animal sources, both primary and secondary, with small input of some marine resources. Only in some specific cases, the nitrogen values were high enough as to suggest significant fish consumption (Bourbou and Richards 2007).

5.2.3.3 Summary

The late medieval Catalan diet was based on cereals, mainly bread made from wheat, barley or millet and millet or sorghum depending on the social status and the religious affiliation. Meat was possibly available that all levels of society; goat was the most esteemed one however cattle and pig were also consumed. On fasting days, fish, cheese and milk were the main source of protein. Marine fish (fresh and possibly dried) and seafood were considered staples. There are very few references to the consumption of freshwater fish which, while considered of high status, may have been exploited by the inland peasants as an easy resource. Pulses and a wide variety of vegetables, fruits and nuts were also available to all levels of the society.

5.2.4 Post-medieval Catalan diet

As it has been described in the review of post medieval English diet review (see section B.4.1.4) after the 16th century, the European diet (including Spanish and

Catalan diet), was significantly changed by the arrival of new foods from the New World such as tomato, potatoes and sweet potatoes, maize, cheap sugar cane, beans and capsicum peppers, artichokes, pumpkins and chocolate (Roden 2012: 33; MacKinnon 2015: 48).

Post-medieval or early modern archaeological research in Catalonia and Spain is almost non-existent. In here, a summary of the only study identified in the present research will be made, but it is worth noting that the majority of the information comes from ethnographical and documentary sources.

5.2.3.1 Archaeological data and documentary sources

In early modern Spain, vegetables were considered to be food for the poor, while the nobility ate great quantities of meat. Suckling pig, baby lamb and veal were the favourite meats but chicken, capons, turkey (introduced in 1523 and consumed for special occasions), guinea hens, geese and rabbits were also consumed. Fruits like cherries, figs, oranges, apples and pears were considered fit for the nobility who also drank wine and hot chocolate (Roden 2012: 40).

Pigs were one of the cornerstones of the peasant diet, although they ate very little at a time. The meat from the annual pig slaughter in November-December was mostly cured to feed the family for the entire year. Reared in rural as well as in urban centres; pigs were fed on left overs (such as maize, potatoes, turnips and cabbage) or left to roam the streets until they were fattened with acorns. Lard was the preferred cooking fat for half of the savoury as well as sweet dishes (Roden 2012: 47). It is probable that the high prevalence of pork in the Spanish cuisine stems from the need to demonstrate allegiance to Catholicism in the times when Islam and Judaism were persecuted by the Inquisition (Roden 2012: 26).

Potatoes, beans, maize and the vegetables from the New World soon replaced the traditional crops of grains, legumes and chestnuts and changed the peasant's diet centuries before they were accepted by the middle and upper classes who considered them poor food or even poisonous. The peasants kept chickens for the eggs, possibly caught wild rabbits and hares or poached wild birds and, in the mountainous regions, caught freshwater fish whenever they could (Roden 2012: 45-46) even if this resource theoretically belonged to the aristocratic landowners.

As in the previous periods, the Catholic Church dominated the diet in the post-medieval Spain and the allegiance to the rules of fasting and abstinence, as well as to the Catholic faith as a whole, was overseen by the Inquisition which was not abolished until 1834. Vegetarian and fish dishes, when they became an acceptable substitute for meat, were the only foods consumed on fasting days. Cod and herring were not only very popular but also were very cheap and easily transported across the country and were eaten by all levels of society. White fish was favoured since the colour was considered to be a sign of purity however salmon, mackerel, whiting and hake were also eaten fresh, salted and preserved. Salted cod was slightly more expensive than fresh fish but it was easy to preserve and kept for long periods, thus it became a common item in the diet of shopkeepers and artisans (Fagan 2006: 244). Other fasting foods were beans, chickpeas, lentils, eggs and dairy products as well as vegetables including potatoes, carrots, turnips and spinach. Drinking chocolate was considered an acceptable fasting food (Fagan 2006: 244; Roden 2012: 40, 43-44).

It is worth noting that depending on the region, Atlantic, Mediterranean or inland, the staples changed considerably. In the Mediterranean area, for example, vegetables and fruit were much more available than in the other two regions (Roden 2012: 48). In this region a combination of oil and animal fat (pork, goose and duck) was the preferred fat to cook (Roden 2012: 80). It seems that in the 16th century, an increase in the price of food in the Kingdom of Valencia may have led the population from a low socio-economic status to a higher consumption of fish, chicken and eggs (Alexander et al. 2015).

In Asturias, at the Spanish Atlantic coast, the agricultural system was based on growing wheat, barley and legumes and rearing sheep and goat. The most important grain for the peasants was rye and barley and, very rarely wheat. Legumes were also part of the diet, mainly beans, peas, chickpeas and lentils which were used for human consumption and, mainly beans also used as pig fodder. Meatless, high-protein, legume-based strews were especially adequate for the fasting days. In the 16th century, potato was introduced to the diet although it would take an entire century for it to be demoted from luxury item to peasant food. Up until the return from the New World, the only C_4 plant cultivated in Spain was millet, however after the return of Columbus, maize was introduced as a crop. By the late 17th century, maize was not only consumed by the locals and their livestock but it was also imported to other countries. Furthermore, due to its quick acclimatisation to the northern Spanish counties and the high calorific density, it soon became a staple for the lowest classes (Tannahill 1973: 241, 246; MacKinnon 2015). B9y the 19th century, the majority of the workers' diet was based on potatoes and bread with the occasional inclusion of meat as a supplement, while the growing middle class had a much more varied diet, most town dwellers consumed very little vegetables and fruit until the early 20th century (Tannahill 1973: 232).

Given the lack of archaeological information available, it is complicated to verify the documentary sources, nevertheless it seems that from the 16th-17th centuries maize entered the diet of the poor classes as a staple or as a fodder. The aristocracy and wealthy populations followed a meat-rich diet supplemented with fish on fasting days, while peasantry and workers possibly relied more on grains, maize and vegetables with the addition of salted cod or mackerel and a very minimal supplement of pork which was possibly fed on C_4 plants.

5.2.3.2 Isotopic investigations of diet

To the author's knowledge, MacKinnon (2015) is the only piece of research investigating the post-medieval diet using human and animal remains from in Spain, more specifically in Asturias (Figure 124). The isotope data obtained from the Asturian animal remains suggest that pigs and goats were fed from food waste and that sheep may have been kept closer to homes. Dogs and rodents also seem to have had a similar diet than humans although most possibly the first one was intentionally fed. The chicken and the small birds show a strong C_4 suggesting they were fed on millet or sorghum or possibly another wild C_4 plant (MacKinnon 2015).

Legend: ● Stable isotope data

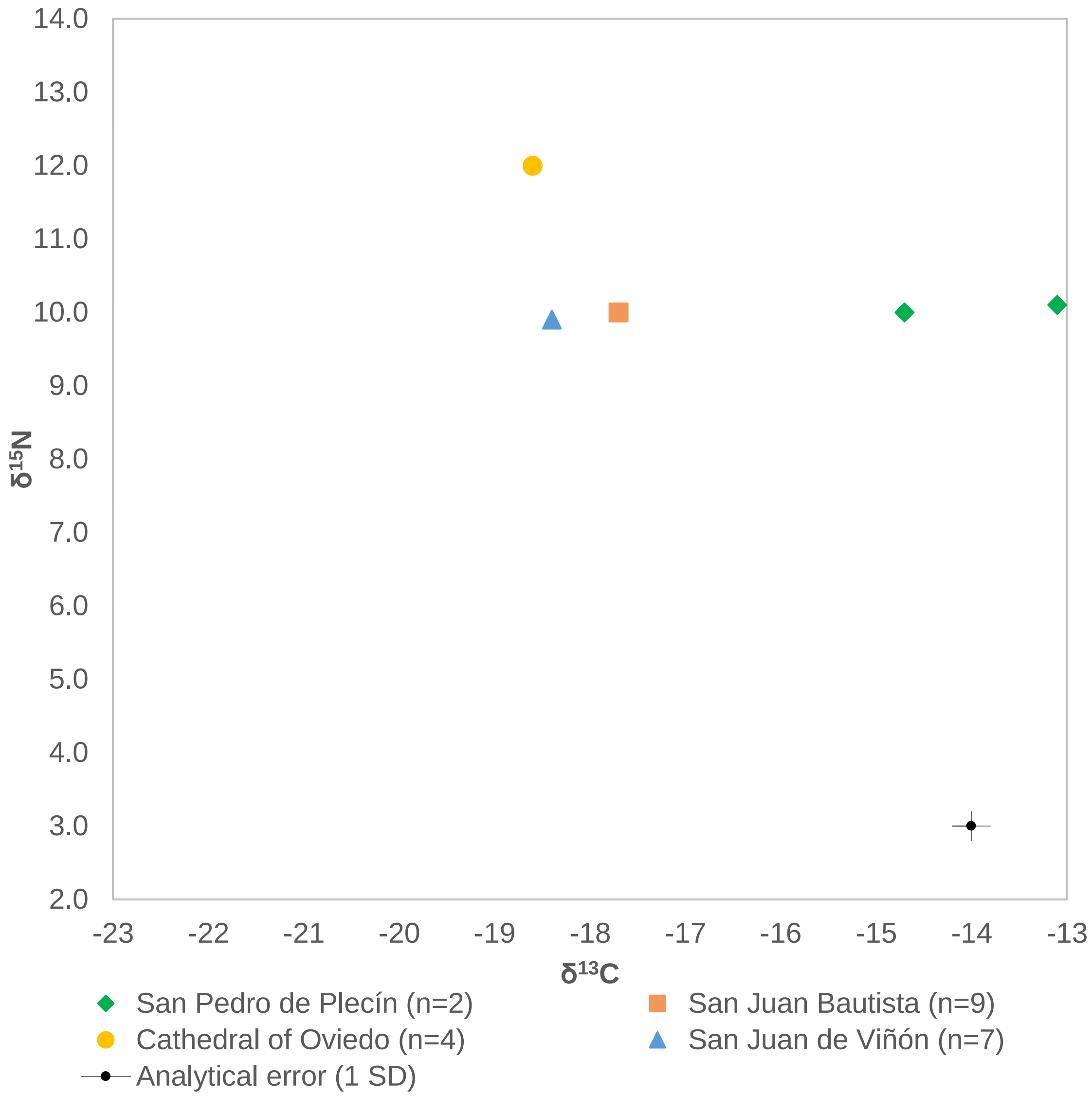
CO: Cathedral of Oviedo; SJB; San Juan Bautista; SJV: San Julián de Viñón; SPP: San Pedro de Plecín.

Figure 124: Location of the north Spanish late medieval sites mentioned in this section

The human samples from this region suggest that diet did change between the late medieval and the post-medieval periods in Asturias. The general trends indicate that medieval populations show higher nitrogen and lower carbon values while the early modern individuals from San Pedro de Plecín, San Juan de Viñón and San Juan Bautista show higher carbon and lower nitrogen rations (Figure 125). This would suggest that the post-medieval population followed a C_3 terrestrial diet supplemented with animal resources or freshwater fish with the possible direct or indirect inclusion of C_4 plants (MacKinnon 2015). The combination of apatite and collagen analysis suggest that maize had a very limited contribution to the carbon enrichment seen in the post medieval samples.

The author suggested that the remoteness of Asturias, which also escaped the Black Death, could be a reason why this maize was no introduced in the diet. Finally, the individuals buried in the medieval Cathedral of Oviedo and the church and hospital of San Juan Bautista show a combination of higher nitrogen and lower carbon values indicative of a diet based on terrestrial C_3 plants combined with freshwater resources, omnivorous and/or weaning animals like suckling pig or kid (Figure 125).

Interestingly, the isotope results from the post medieval population of Asturias does not seem to reflect the drastic change of diet expected for this period. However it is very possible that the uniqueness of this population may have biased this interpretation therefore many more studies will be needed to evaluate how the new imports affected the diet of the different social classes.



Graph by author. Data from: MacKinnon (2015). Data represented as discussed by the author. Multiple data points represent different sub-groups. Each data point represents the mean average of the sample.

Figure 125: Isotope signature for the north Spanish sites referred in the text

5.2.4.3 Summary

Documentary sources suggest that post-medieval Spanish diet was very class-specific. Potatoes, beans, maize, vegetables from the New World, small amounts of meat (mainly pig but also chicken and eggs) freshwater fish and cod and herring defined the diet of the poor while vast amounts of meat, white fish, fruit, wine and chocolate and small amounts of vegetables defined the diet of the wealthy who also resisted the adoption of the New World products. It must be taken into account that diet staples changed between regions, with the Mediterranean coast relying more heavily on vegetables and fruit and possibly chicken, fish and eggs. Thus the post-medieval diet was a C_3 terrestrial diet supplemented with animal resources or freshwater fish with the possible direct or indirect variable inclusion of C_4 plants.

Appendix 6: Stable isotope analysis

This chapter will provide an overview on the composition of the bone collagen and its physiology, a short review of the bio-geochemical routes of carbon and nitrogen in terrestrial and marine environments and of the main factors influencing isotope values.

6.1 Collagen composition and carbon and nitrogen metabolism

6.1.1 Proteins, amino acids and collagen

Proteins are organic structures made from the combination of 20 different amino acids formed by a carbon skeleton (including an NH_2-group) and a variable part that defines its chemical and physical characteristics. Amino acids are divided in two categories depending on the ability of the organism to synthesise the carbon skeleton: the skeleton of non-essential amino acids can be synthesised *de novo* or modified by the organism while that of the essential amino acids cannot be and thus it must be obtained through diet (Schoeller 1999). Because of these different assimilation and physiological pathways, essential amino acids reflect the isotope signature of the diet (and thus are increasingly being used to solve complex dietary reconstructions) while non-essential amino acids are influenced by the metabolic isotopic fractionation (Webb et al. 2015).

Collagen is the most abundant protein in animals and in humans as it constitutes a third of the total body protein (Shoulders and Raines 2009). It is formed by three staggered poly-proline strands forming a right-handed triple helix bound by hydrogen bonds (Pauling and Corey 1951; Ramachandran and Kartha 1955). A third of the amino acids composition is glycine and around 22% of its residues are either proline or hydroxyproline, a hydroxylated form of proline which contributes to the thermo-stability of the chain (Shoulders and Raines 2009). There are 28 types of collagen, although fibrillary Type I, found in bone, skin, dentine and tendon, is the most important. Collagen Type I has a very high tensile strength, is almost insoluble, thermostable and able to interact with other biomolecules (Schwarcz and Schoeninger 1991; Shoulders and Raines 2009). Furthermore, research in living animals under strictly controlled diet has shown that, in a balanced diet, the dietary protein is the main contributor to the formation of bone collagen. Thus by isotopically analysing bone collagen, we are getting an insight on the origin of the *protein* over the last 5-15 years of life (Richards and Hedges 1999).

6.1.2 Carbon and nitrogen metabolism

Krueger and Sullivan's (1984) model on the relationship between diet and collagen proposed that all the carbon in bone collagen originated from the protein fraction of the diet. In contrast, the mineral component of the bone, hydroxyapatite, reflected the values of the whole diet (Jim et al. 2004). In regards to nitrogen, 98% of it is locked in proteins and amino acids, with the remaining 2% forming part of nucleic acid, urea and ammonia. When protein is ingested, the stomach acids break it down to amino acids or peptide chains and absorbed; 75% will be retained while the remaining will be transformed into ammonia and then to urea before being transferred to the blood stream and excreted (Schoeller 1999). The nitrogen enrichment observed between trophic levels (see section B.6.2.3) results from the preferential use of ^{14}N amines to produce urea thus creating a ^{14}N-higher urea and a ^{15}N-higher body tissues (Schwarcz and

Schoeninger 1991). This means that as nitrogen's isotopic signature depend, not only on the diet, but also on the fractionation during assimilation, metabolic processes and excretion patterns, a retrospective estimation of dietary amounts of meat or fish based on $\delta^{15}N$ values of human remains is extremely difficult (Huelsemann et al. 2013).

6.2 Review of light stable isotope analysis in dietary reconstruction

6.2.1 Introduction

The nucleus of an atom is composed by protons, which define the *element*, and neutrons, that define the *isotope* of this element. The *light isotope* is the more naturally abundant form of the element but some atoms can have one or two extra neutrons. This addition will increase the isotope's atomic mass and thus these isotopes are referred as *heavy.* The attribute "stable" given to the hydrogen, carbon, nitrogen and oxygen's isotopes refer to their non-radioactive nature. These isotopes do not decay and become other elements through time, thus the stable isotope composition of bone or tooth will remain unchanged unless diagenetic process or contamination affect the sample (Ambrose 1993).

The increased weight of the heavy isotope does not influence its chemical behaviour, but its kinetic and thermodynamic properties are altered meaning that molecules containing heavy isotopes will move between bio- and geochemical stages at a different speed than the molecules containing only light isotopes (Schwarcz and Schoeninger 1991). *Isotopic fractionation* is the quantifiable variation in the relative abundance of the heavy isotopes compared to the light isotopes in the different reservoirs (Schoeller 1999) and is directly dependant on the difference in weight between the light and the heavy isotopes. The greatest the difference in weight, the greatest the fractionation will be, thus hydrogen, the lighter of all elements will show the largest isotopic fractionation (Pollard and Wilson 2001).

The difference in abundance between the light and the heavy forms of isotopes is so significant that abundance of the heavy isotopes is only measureable with high precision instrumentation and shown as a relative ratio to the light isotope (e.g. $^{13}C/^{12}C$ or $^{15}N/^{14}N$) using the delta (δ) per mil (‰) notation. The ratio is calculated with the following formula:

$$\delta = [R_{sample} - R_{standard}) / R_{sample}] \text{ X } 1000$$

Where R is the ratio of the heavy to the light isotope (e.g. $^{13}C/^{12}C$) in the sample and in the international standard (Peedee Belemnite Limestone (PDB) for carbon and Air for nitrogen) (Schwarcz and Schoeninger 1991).

6.2.2 Nitrogen and carbon in terrestrial, marine and lacustrine environments

The use of carbon and nitrogen stable isotopes as a proxy for diet reconstruction is based on the assumption that the isotopic composition of the animal/human tissue is a constant and direct reflex of that of the diet (Ambrose 1993). However to use this type of data to produce a faithful dietary reconstruction, accurate information about the type of sample, the environment and climate the animal/human had lived in, the isotopic composition of all the dietary resources available as well as any cultural practice that would have influenced the dietary habits of the individual or community under study is required. It should be considered whether there is any possibility that diagenetic processes may have affected the isotopic composition of the sample. Here, an overview of the shifts in the $\delta^{13}C$ and $\delta^{15}N$ values in terrestrial and marine environments and the factors influencing these shifts is presented.

B.6.2.2.1 $\delta^{13}C$ and $\delta^{15}N$ in terrestrial environments

Atmospheric CO_2, with a $\delta^{13}C$ value between -7 and -8‰, is the main source of carbon for terrestrial green plants that introduce the carbon to the biological system through photosynthesis. Depending on the size of the first metabolite after the CO_2 fixation, all plants can be classified in three groups: C_3, C_4 and CAM (Crassulacean Acid Metabolism). In C_3 and C_4 pathways, the first molecule has three and four carbon atoms respectively. CAM plants (e.g. pineapple or aloe), can use C_3 and C_4 photosynthetic pathways depending on the environmental conditions (Schwarcz and Schoeninger 1991). Since CAM are found in very warm and dry environments and are not part of the natural flora of England or Catalonia, they will not be discussed further.

The C_3 pathway is used by all trees, woody shrubs, temperate grasses (e.g. wheat, rice, forest, montane and wetland grasses) and by all root crops, legumes, vegetables, nuts and most fruits (Pollard and Wilson 2001). These plants grow better in shaded, cool and wet climates and high altitude and high latitude environments. In contrast those plants that grow best in hot, sunny and dry microhabitats with high temperatures and strong sun light during the growing season, for example, sorghum, millets, maize, cane sugar, use the C_4 pathway (Ambrose 1993).

C_3 plants discriminate against atmospheric $^{13}CO_2$ more than C_4 plants (i.e. are less prone to capture atmospheric the heavy CO_2). Thus the $\delta^{13}C$ value C_3 plants is around -26.5‰, while C_4 plants have an average $\delta^{13}C$ value of -12.5‰. The $\delta^{13}C$-ranges for C_3 and C_4 plants do not overlap and, as plants are at the base of the food pyramid, their different carbon isotope signature will be transported to the animals that feed on them. The differentiation between these two types of pathways and plants is important because in regions like Catalonia where millet is an autochthonous plant (see B.4.2), the carbon values for the herein analysed Roman population analysed could reflect at least a small input of C_4 plants.

The majority of the nitrogen is bound as N_2 in the atmosphere and most of it enters the biological system through the N_2–fixation by bacteria in nodules on terrestrial plant roots. Legumes obtain most of their nitrogen by bacterial N_2–fixation and so have $\delta^{15}N$ values close to the atmospheric values (i.e. 0‰) however most terrestrial plants can also obtain nitrogen via bacterial nitrification and denitrification of nitrogen-containing molecules on organic matter and thus show a wider range of $\delta^{15}N$ values (Schwarcz and Schoeninger 1991).

B.6.2.2.2 $\delta^{13}C$ and $\delta^{15}N$ in marine environments

The majority of the CO_2 is dissolved in the ocean, which has a $\delta^{13}C$ value of 0‰, and is introduced in the biological system thanks to the photosynthetic activity of the phytoplankton. Sea grasses have $\delta^{13}C$ similar to the C_4 plants while most planktonic species providing food for the higher organisms have a $\delta^{13}C$ value between C_3 and C_4 plants thus the majority of the marine vertebrates show intermediate C_3-C_4 $\delta^{13}C$ values, averaging at -19‰ (Schwarcz and Schoeninger 1991).

The N_2 dissolved in aquatic systems (ocean, rivers, lakes and swamps) enters the biological system as a result of N_2-fixing reactions by blue/green algae and bacteria which produce higher nitrogen-containing molecules. This enrichment is passed up to the food chain so marine organism and its consumers tend to have much higher $\delta^{15}N$ values than terrestrial ones (Schwarcz and Schoeninger 1991). Also, marine food chains are longer than terrestrial ones resulting in marine nitrogen isotope values significantly higher compared to the terrestrial values.

In coastal areas as well as in lakes and rivers, the carbon available for the aquatic plants can come from several sources including terrestrial waste washed to the ocean thus the carbon isotopic values is a mixture of terrestrial plants, dissolved and atmospheric CO_2. The resulting $\delta^{13}C$ values from plants and fish living in these environments overlap with the terrestrial values and resembling the values obtained from C_3 plants (Schwarcz and Schoeninger 1991). Thus Hedges and Reynard (2007) suggested that the combination of higher $\delta^{15}N$ and lower $\delta^{13}C$ in collagen could indicate a freshwater fish component in the diet. However Dufour and colleagues (1999) showed that carbon and nitrogen values obtained from modern freshwater fish from different European lakes can vary significantly (~12.5‰ and ~8.0‰, respectively) and that same species living in different lakes could also show significantly different isotopic values possibly reflexing of the specific environmental conditions of each lacustrine system (Dufour et al 1999). Schoeninger's et al. (1983) $\delta^{15}N$ values from freshwater fish bone collagen ranged between +6.6 and +9.5‰ thus also overlapping with the higher values obtained from terrestrial food sources and making it complicated to distinguish between these two types of food sources.

6.2.3 Trophic level effect

The “trophic effect” is the isotopic offset between two reservoirs or taxa or between diet and tissue. It is represented by Δ and is calculated with the following equation (based on Bocherens and Drucker 2003), where A is the origin/producers and B the destination/consumers:

$$\Delta^{13}C_{A\text{-}B} = \delta^{13}C_B - \delta^{13}C_A \text{ or } \Delta^{15}N_{A\text{-}B} = \delta^{15}N_B - \delta^{15}N_A$$

Carbon and nitrogen isotopic values are known to increase in each step of the food chain, however the mechanisms of the diet to body isotope signature transfer as well as the scale of this enrichment remains poorly understood (O'Connell et al. 2012). Nevertheless, as the $\Delta^{13}C$ of 1‰ from producers to consumers is too small to be useful to evaluate the consumer’s position in the food chain (Schoeninger and DeNiro 1984; Schwarcz and Schoeninger 1991), thus position is usually determined by the nitrogen values. An average $\Delta^{15}N$ of 2.54±0.11‰ between taxa including mammals, birds, crustaceans, insects, fishes, molluscs and spiders was estimated in a meta-analysis review from 32 publications (Vanderklift and Ponsard 2003) however, the majority of the studies consider that the average $\delta^{15}N$ enrichment between trophic levels is around +3-4‰ (Hedges and Reynard 2007; O'Connell et al. 2012). In humans, this value can vary between 1.8 and 6‰ (Huelsemann et al. 2013). The reason for this substantial shift is poorly understood but while some attempts have been made to quantify the $\Delta^{15}N_{diet-body}$ in humans, as target tissues (bone collagen, hair keratin and blood proteins) reflect medium or long-term dietary patterns; these short-term experimental diet changes are not easily identified (see summary in O'Connell et al. 2012). In a novel approach, O'Connell et al. (2012) matched the isotopically controlled diet to the normal diet of each individual subject and measured the $\Delta^{15}N_{diet-body}$. Starting from in red blood cells, the authors estimated a $\Delta^{15}N_{diet-collagen}$ range of +5.9-6.3‰ with their most conservative scenario producing an $\Delta^{15}N_{diet-collagen}$ of +4.6‰, a significantly larger offset than the 3‰ assumed in most of the studies. From a prospective of reconstruction of past diets, these results imply that, in most cases, the input of high trophic level foods (e.g. meat, milk and fish) in the diet has been a consistently overestimated.

The $\Delta^{13}C$ of 7‰ between seawater bicarbonate and atmospheric CO_2 is maintained along the trophic levels (Dufour et al. 1999). This difference should, theoretically be big enough to allow the distinction between consumers of marine or terrestrial foods as the first should produce values between -12 and -14‰ while the carbon signature of the latter would be dependent on the crop grown in the area (Schoeninger et al. 1983). However the carbon isotope values of marine and terrestrial feeders overlap if herbivores feed on C_4 grasses. Then $\delta^{13}C$ can be used to differentiate between marine and terrestrial resources only when C_4 plants are not available (Schoeninger and DeNiro 1984).

Similarly, the nitrogen values of marine environments are, on average, 9‰ higher compared to the terrestrial ones (Schoeninger and DeNiro 1984). Schoeninger and colleagues (1983) showed that historic populations highly reliant on marine resources had significantly higher collagen $\delta^{15}N$ than the agriculturalists. For example Alaskan Eskimos' $\delta^{15}N$ values range between +17 and +20‰ and the mean values for the Mugu hunter-gatherers and the Mesolithic Danish fish-gatherers are +16‰ and +14‰, respectively. Interestingly, the Bahamian population had a much lower $\delta^{15}N$ value of +11‰ possibly as a result of the coral reefs fixing larger amounts of nitrogen. In contrast, the $\delta^{15}N$ values for the North American agriculturalists ranged between +6 and +12‰ and the average obtained from the Mesoamerican maize reliant agriculturalists was of +9‰ (Schoeninger and colleagues 1983).

To carry out a reliable diet reconstruction of past populations, the isotope composition of all the possible available foodstuff should be analysed (Schwarcz and Schoeninger 1991; Dufour et al. 1999). And as the $\delta^{13}C$ and $\delta^{15}N$ values between the different food sources can overlap, ideally, to obtain the best diet possible reconstruction, the isotopic values of both elements should be used in combination.

6.2.4 Factors influencing the isotope signature

B.6.2.4.1 Endogenous factors, health and disease

There is no age- or sex-dependant carbon or nitrogen physiological difference therefore any change in the isotope ratios observed in the archaeological population must be related to an actual variation of diet between the different population subgroups (Schwarcz and Schoeninger 1991). However human nitrogen isotopic vary under different conditions such as pregnancy, growth, illness, physiological stress (Katzenberg and Lovell 1999; Fuller et al. 2004; Fuller et al. 2006; Waters-Rist and Katzenberg 2010; Beaumont et al. 2015; D'Ortenzio et al. 2015) and even in low-protein diets where the reduction in urinary excretion of nitrogen will influence the nitrogen ratios (Steffee et al. 1976).

Finally, there is no evidence for a variation in isotopic fractionation between different skeletal elements even though the turnover might differ between bone elements (Schwarcz and Schoeninger 1991). It is widely accepted that the slower femoral turnover reflects the average diet of the previous 10-20 years while the quick renovation of the ribs reflect the diet of the last two years. Thus the rib values might register the dietary changes faster than the femur (Fuller et al. 2006), providing a snapshot of the last two years of life.

6.2.4.2 Climate

As the magnitude of isotopic fractionation decreases with increasing temperatures, local climate as well as altitude and aridity are factors to be considered when intending to carry out a diet reconstruction (Schwarcz and Schoeninger 1991). For example, nitrogen isotope values in very warm climates they are significantly higher than the values found in more temperate countries (Ambrose 1993). Also draught-resistant African herbivores show higher the $\delta^{15}N$ values (Ambrose 1991) although this value is very variable and also depends on the protein intake and the metabolism of the animal (Schwarcz and Schoeninger 1991).

As temperature affects the fractionation of CO_2, $\delta^{13}C$ values can also change depending on latitude. For example, in Scotland the average carbon value is 27.5‰ while in the Mediterranean area is -24.7‰. Consequently, individuals from the Mediterranean area with a complete terrestrial diet will have $\delta^{13}C$ values of around -18‰ while northern Europeans will have values around -20‰ (Richards and van Klinken 1997). The effect of climate on isotope fractionation is therefore important to consider when comparing populations from different areas and when carrying out a dietary reconstruction as this shift can influence the apparent position in the trophic chain or modify the interpretation of the isotopic results.

6.2.4.3 Manuring and use of fertilizers

Huelsemann's et al. (2013) reported that vegetables grown using synthetic, unknown or without fertiliser yielded a mean $\delta^{15}N$ value of 3.1‰ while vegetables from organic farming produced values of 6.8±3.6‰ and those grown in fields treated with animal manure of 9.8±3.8‰. Similarly, Bol et al. (2005) reported no significant difference in the ^{13}C content when comparing soils treated with animal or mineral manure and untreated soil, but a significant increase from 4.7±0.13‰ to 5.8±0.18‰ between untreated and manured soil. Mineral fertilisers did not change the soil's nitrogen isotope value ($\delta^{15}N$ 4.4±0.15‰). Kanstrup et al. (2011) also showed that while $\delta^{13}C$ values were similar in manured and non-manured soils, $\delta^{15}N$ the values in manured soil were significantly higher compared to the values observed in non-manured or in phosphorus-potassium fertilised soils (between +6.8 and 6.2‰, +4.9 and +4.3‰ and +5.1 and +4.5‰, respectively).

This "manuring effect" is related to the preferential loss of ^{14}N in volatile gaseous ammonia (NH_3) in animals; increasing the ^{15}N in the residual ammonium (NH_4) that will be converted to higher nitrate; which, in its turn, is the main source of nitrogen for the biosynthesis of plant amino acids (Bogaard et al. 2007).

Thus manuring is an anthropological soil modification that can have a direct effect on the crop's $\delta^{15}N$ value. Although nowadays animal-derived manure is not extensively used, it is very possible that in the past, this was one of the most common ways of increasing the productivity of the fields and to restore soil's nutrients along with other methods like burning of the native vegetation, the application of nutrient higher plant residues and sediments or domestic waste (Bogaard et al. 2007; Kanstrup et al. 2011). These anthropogenic practices would have affected the herbivores and human's nitrogen values thus potentially altering the interpretation of the type of diet proposed for a specific population. For example, the average $\delta^{15}N$ values above 9‰ observed in Early Neolithic populations (Richards 2000; Schulting and Richards 2002) was interpreted as suggestive of an animal-based or a mixed plant and animal diet. This hypothesis is valid assuming that the trophic level enrichment is +3‰ and the plant value is around +3‰. In this scenario, a completely vegetarian individual should have $\delta^{15}N$ values of around +6‰, carnivore individuals of around +9‰ and omnivorous individuals between +6 and +9‰. However if fields had been annually manured, cereal grains would show $\delta^{15}N$ values between +6 and +8‰ and if the trophic shift is still considered +3‰, the consumers' values would lie between +9 and +11‰, thus resembling a largely animal-based diet. In biennial manured crops, the $\delta^{15}N$ values fell between +3 and +6‰ and thus the consumers' values, between +6 and +9‰, could be misinterpreted as a mixed plant and animal diet (Bogaard et al. 2007). Thus not only manuring but also the frequency of manuring has an impact on the $\delta^{15}N$ values in plants, herbivores and humans (Bogaard et al. 2007; Kanstrup et al. 2011).

6.2.4.4. Diagenesis and contamination: definition and effect on isotopic ratios

Diagenesis is the degradation or reduction in the quantity of collagen extracted from the bone due to the gradual breakup of the collagen chains. It happens without the intervention with any pollutant and is a particular problem in tropical areas, United States and Africa. Degradation does not necessary affect the isotopic ratio but will affect the yield thus a bigger sample size should be considered if there is the possibility of the bone being degraded. This would ensure the final sample to be big enough to allow the identification small isotopic variations.

Contamination is the presence of exogenous contaminants on the bone, this is a problem in temperate areas where while climatic conditions might not affect the collagen yields. However foreign natural and man-made pollutants (e.g. humics and resins, respectively) can be problematic if they penetrate the bone matrix, bind to the collagen and form large molecules.

Traditionally, the C:N ratio estimated from the amino acid composition of collagen has been used as an indicator of the quality of the collagen (van Klinken 1999). Its exact value is 3.21 but it can vary between 2.9 and 3.6 in bone samples prepared for isotopic analysis. Values between 3.4 and 3.6 can reflect contamination by lipids, carbonates, humic acids or other carbonic substances (Ambrose 1993). However Schwarcz and Shoeninger (1991) argued that if the bone surface appeared well preserved, the sample had been chemically and mechanically cleaned and the analysis showed more than 5% of collagen in the original bone weight, then the sample could be considered as being of good quality.

Both, diagenesis and contamination can potentially affect the isotopic concentration or change the isotopic values of the collagen and thus when carrying out an isotope analysis, they should be taken into account as the can affect the palaeodietary interpretation (van Klinken 1999).

6.2.5 Animal baselines

One of the main problems when attempting a diet reconstruction of past populations is a conspicuous lack of isotopic data from common food components. Usually, studies analysing human remains also include faunal data to adequately contextualise the human isotope values results. However there has not been a systematic isotopic study of faunal remains with known dietary base and environmental conditions. Furthermore, as vegetable remains hardly ever survive most of the ^{15}N baseline is built only from the faunal remains, with herbivore data taken as an indicator of the ^{15}N values of the vegetation. For this data to be reliable, the animal and human samples should also be contemporaneous and, ideally, extracted from close geographical areas, a requirement which is, in many cases, not possible. The result is a lack of a comprehensive database affects the interpretation of the bone isotopic results (Hedges and Reynard 2007).

Hueslemann and colleagues (2013) analysed several modern foods and compared it to data obtained from the literature in one of the latest attempts to evaluate the isotopic variability in different food categories (Table 79). While it is an important improvement, this modern data does not compensate for the lack of archaeological faunal and botanical isotopic data.

Table 79: Modern Food Data (obtained from Huelsemann et al. 2013)

	Experimental	Literature
Plant food		
Cereals C3	3.2±0.7	3.2±1.3
Cereals C4	3.5±0.7	3.3±1.9
Vegetables without fertilizer	3.1±2.4	3.1±3.0
Vegetables with organic fertilizer	-	6.8±3.9
Vegetables with animal fertiliser	-	9.8±3.8
Legumes	1.5±1.5	1.1±1.8
Potato	4.4	3.1±3.4
Rice	5.9	5.0±1.7
Fruit	3.4±1.9	4.6±2.4
Nuts	3.6±2.8	2.7±2.1
Cacao	5.7±1.1	-
Yeast	1.1±0.3	1.3±0.3
Meat and related products		
Pork and related products	4.5±0.7	4.5±1.1
Poultry	3.1±0.9	2.8±1.0
Beef	6.1±0.8	6.6±1.0
Lamb	7.0±0.9	5.7±1.4
Eggs	4.7±0.4	5.1±0.8
Dairy	5.9±1.0	5.3±0.9
Marine Fish		
Pollock (Pacific, Alaska)	13.6±1.4	13.2±1.1
Herring (Pacific and Atlantic)	11.5±1.7	12.8±1.0
Salmon (N. and S. America and N. Europe)	11.3±1.4	12.0±1.5
Hake	13.3±0.5	12.8±2.5
Cod	15.7	14.4±2.2
Flatfish	15±1.4	13.6±1.5
Tuna	12.3±1.8	12.6±2.2
Mackerel	9.6±0.1	12.1±2.5
Pilchard	9	12.0±3.5
Shellfish	9.8±3.8	10.4±3.0
Squid	11.3±2.9	12.4±2.3
Freshwater Fish		
Carp	10	10.2±2.5
Trout	11.8±1.3	10.3±1.8
Catfish	5.1	10.4±0.9
Perch	13.9±3.1	10.7±46

6.2.6 Summary

Carbon isotope can be used to differentiate between diets based on C_3 or C_4 plants as well as terrestrial *versus* marine diets as C_4 plants and marine-based diets show higher carbon value compared to the C_3 plants and terrestrial-based diets. In contrast, nitrogen values can help to position the individual within the trophic chain and to identify the source of the protein as marine resources show higher nitrogen values compared to the terrestrial sources. However it should also be noted that many ranges to sometimes overlap and that intermediate marine-terrestrial isotope values (e.g. freshwater resources) could easily be masked by a stronger terrestrial or marine signature. Therefore to attempt a dietary reconstruction, a geographically and temporally relevant animal baseline should be used to contextualise the results. And finally, the impact of isotope fractionation influencing factors such as cultural practices and health status, climate and agricultural techniques should be considered.

Appendix 7: Results Part B.5: Supporting tables.

For all this section:

Sex categories: M: male, F: female, I: indeterminate.

Age categories: Y: young adult, M: middle adult; O: old adult, A: adult.

Extra-spinal manifestations: N. obs: not observable

7.1 Individuals from the Romano-British sites of Baldock, Gambier Parry Lodge and Kingsholm

						Extra-spinal manifestations (mm.)					
Site	Ind.	Sex	Age (95%)	Y/M/O	DISH	R olec.	L olec.	R pat.	L pat.	R calc.	L calc.
Baldock	Bal 1022	F	63.5	O	N	uneven	uneven	-	spicules	1.9	4.3
	Bal 1028	F	32.3	Y	N	smooth	smooth	-	smooth	smooth	smooth
	Bal 1040	F	61.8	O	N	-	-	-	-	-	-
	Bal 1049	M	75.6	O	Stage 2	-	-	7.2	6.1	1.8	-
	Bal 1072	M	47.0	M	Poss Stage 1	smooth	smooth	7	4.1	4.5	spicules
	Bal 1077	F	75.1	O	N	smooth	smooth	spicules	spicules	-	-
	Bal 1090	M	48.6	M	N	-	uneven	uneven	uneven	uneven	uneven
	Bal 1107	F	71.0	O	N	smooth	-	-	smooth	spicules	-
	Bal 1122	F	80.0	O	Stage 4	2.8	3.5	spicules	5.5	-	3.2
	Bal 1174	M	28.9	Y	N	-	smooth	spicules	uneven	uneven	spicules
	Bal 1203	M	72.5	O	N	smooth	uneven	spicules	spicules	4.1	2.4
	Bal 1237	M	75.9	O	N	2	-	3.4	spicules	-	3.4
	Bal 1263	M?	A	A	N	-	-	-	-	-	-
	Bal 1281	F	73.1	O	N	spicules	uneven	uneven	uneven	spicules	spicules
	Bal 1319	F	68.6	O	N	-	uneven	uneven	uneven	spicules	spicules
	Bal 1320	M	41.4	M	N	spicules	spicules	uneven	spicules	4.1	5.1
	Bal 1342	I	64.1	O	N	-	-	-	-	-	2.7
	Bal 1372	M	70.6	O	N	uneven	uneven	uneven	uneven	spicules	-
	Bal 1374	M	74.3	O	Stage 2	uneven	-	-	-	-	-
	Bal 1391	F	62.5	O	N	uneven	uneven	uneven	spicules	-	spicules

Cont...

Table 7.1 cont...

	Bal 1446	F	39.2	Y	N	uneven	-	uneven	uneven	spicules	-
	Bal 1447	F	38.3	Y	N	-	-	smooth	smooth	-	-
	Bal 1480	M	29.9	Y	N	uneven	uneven	-	spicules	-	-
	Bal 1487	F	69.2	O	N	spicules	uneven	uneven	uneven	spicules	spicules
	Bal 2225	M	45.8	M	Stage 2	uneven	uneven	uneven	uneven	uneven	uneven
	Bal 2602	F?	82.1	O	N	2.2	2.3	spicules	5.2	7.1	-
	Bal 3644	M	37.5	Y	N	spicules	spicules	spicules	2.1	spicules	spicules
	Bal 883	M	31.1	Y	N	1.7	-	uneven	spicules	spicules	-
	Bal F18 L10	M	33.8	Y	N	spicules	spicules	-	-	2.9	3.3
	Bal F466	M	39.4	Y	N	4.8	spicules	smooth	4	3.7	6.3
	Bal F475 L2	M	73.2	O	N	-	spicules	spicules	5.4	2.5	3.1
	Bal F557 L2	F	73.5	O	N	smooth	uneven	uneven	-	-	spicules
	Bal F610 L1	F	26.7	Y	N	uneven	uneven	spicules	spicules	6.3	3.9
	Bal F644	F	74.5	O	N	uneven	uneven	uneven	uneven	1.8	spicules
	Bal F653	F	A	A	N	uneven	-	-	-	3.2	2.6
	Bal F92	M	79.7	O	Stage 4	uneven	spicules	spicules	spicules	-	spicules
	500	M	28.4	Y	N	smooth	-	-	-	uneven	uneven
	510	I	27.3	Y	N	uneven	-	uneven	-	spicules	spicules
	518	M	24.7	Y	N	3.5	2.6-3.9	uneven	2.5	spicules	uneven
	520	F	58.9	M	N	-	-	spicules	-	3.9-5.2	2.5
	524	M	70.8	O	N	smooth	-	-	uneven	-	-
	525	M	76.7	O	Stage 4	uneven	uneven	4.2	spicules	spicules	spicules
	529	M	63.9	O	N	spicules	uneven	2.3	spicules	-	-
	530	F	21.1	Y	N	smooth	smooth	smooth	smooth	-	smooth
Gambier Parry Lodge	533	F	15	A	N	-	-	-	-	-	-
	536	F	72.9	O	N	-	uneven	-	-	-	-
	543	I	A	A	N	-	smooth	-	-	-	-
	545	M	69.9	O	N	uneven	spicules	-	-	spicules	spicules
	549	M	38.8	Y	N	uneven	smooth	-	spicules	-	spicules
	553	F	82.2	O	N	-	uneven	uneven	uneven	-	spicules
	561	M	22.6	Y	N	uneven	uneven	-	spicules	-	-
	567	I	29.6	Y	N	uneven	-	-	-	-	-
	568	F	26.1	Y	N	uneven	uneven	smooth	smooth	-	-
	571	F	36.7	Y	N	-	-	-	-	-	-

Table 7.1 cont...

	572	M	58.9	M	N	spicules	2.5	uneven	spicules	spicules	-
	577	F	32.3	Y	N	smooth	uneven	uneven	uneven	-	-
	582	I	65.1	O	N	smooth	smooth	smooth	smooth	-	-
	583	I	46.1	M	N	smooth	smooth	-	uneven	spicules	spicules
	585	F	15	A	N	smooth	smooth	smooth	-	-	-
	35K 10	F	70	O	N	uneven	-	smooth	smooth	-	-
Kingsholm	K112	M	47.5	M	N	uneven	uneven	-	-	-	-
	K154	F	28.1	Y	N	smooth	uneven	-	-	uneven	uneven
	K166a	F	36.3	Y	N	2	spicules	-	smooth	-	-
	K208	F	31.3	Y	N	uneven	uneven	uneven	smooth	spicules	spicules
	K213	M	67	O	N	uneven	smooth	3.4	uneven	uneven	uneven
	K215	F	37	Y	N	smooth	smooth	spicules	uneven	uneven	-
	K234	F	39.1	Y	N	uneven	uneven	-	uneven	-	-
	K251	F	67	O	N	uneven	uneven	2.8	uneven	2.8	-
	K292	F	42.1	M	N	2	uneven	spicules	spicules	spicules	spicules
	K31	M	15	A	N	Smooth	Smooth	-.	-	Smooth	Smooth
	K415	I	39.9	Y	N	smooth	smooth	-	-	-	-
	K54	F	35.4	Y	N	smooth	-	-	spicules	-	-
	K92	F	59.1	M	N	smooth	smooth	-	uneven	spicules	spicules
	K96	M	26.9	Y	N	spicules	uneven	spicules	2.2	2.8	spicules

7.2 Individuals from the Roman Catalan sites of Tarraco and Santa Caterina

						Extra-spinal enthesopathies (mm.)					
Site	**Ind.**	**Sex**	**Age (95%)**	**Y/M/O**	**DISH**	**R olec.**	**L olec.**	**R pat.**	**L pat.**	**R calc.**	**L calc.**
Santa Caterina	001-01-745	I	39.1	Y	N	-	-	-	-	-	-
	001-01-748	F?	77.3	O	N	-	2.6	spicules	-	-	-
	001-01-754	F?	77	O	Poss Stage 1	-	-	-	-	-	-
	001-01-755	F	71.4	O	N	smooth	smooth	-	-	-	-
	001-01-756	M	74.1	O	Poss Stage 2	uneven	smooth	-	-	-	-
	001-01-757	I	15	A	N	5.4	smooth	-	-	-	-
	001-01-758	F	15	A	N	smooth	smooth	-	-	3.4	4.1
	002-00-704	F?	A	A	N	-	-	-	-	-	-
	002-00-706	M	47.6	M	N	smooth	smooth	-	-	-	-

Cont...

Table 7.2 cont...

002-00-707	F	54.2	M	N	uneven	uneven	-	-	-	-
002-00-708	F	26.7	Y	N	uneven	-	-	-	spicules	spicules
002-00-709	M	76	O	N	-	smooth	-	-	spicules	spicules
002-00-710	M	15	A	N	smooth	uneven	spicules	spicules	smooth	-
002-00-711	F?	78.6	O	N	-	smooth	-	-	-	-
002-00-719	M	71.7	O	N	smooth	-	-	-	-	-
002-00-721	I	18.3	A	N	smooth	smooth	-	-	smooth	smooth
002-00-725	F	66.3	O	N	2.7	1.8	-	uneven	uneven	uneven
002-00-727	M	75.6	O	Poss Stage 1	smooth	smooth	smooth	smooth	spicules	spicules
002-00-729	F	74.6	O	N	smooth	4.2	-	-	-	-
002-00-731	M	38.5	Y	N	uneven	uneven	-	2.5	spicules	spicules
002-00-732	F	32.7	Y	N	-	smooth	-	-	spicules	spicules
002-00-733	F	35.4	Y	N	smooth	smooth	-	spicules	spicules	spicules
010-04-T14	M	75.9	O	N	-	smooth	smooth	smooth	-	-
010-04-T15	M	72.4	O	N	-	-	-	spicules	-	-
010-04-T18	M	70.8	O	N	-	uneven	-	-	-	-
010-04-T3	M	38.1	Y	N	uneven	uneven	spicules	-	-	spicules
010-04-T8	F	60.1	O	N	-	-	-	-	spicules	spicules
024-04-UE1114	I	A	A	N	-	-	-	-	-	-
072-84-Q4.90	I	73.3	O	N	-	smooth	uneven	-	-	-
072-84-Q4.96	F	68.4	O	N	-	uneven	-	spicules	-	spicules
072-86-A1.124	M	71.5	O	N	uneven	uneven	spicules	uneven	2.5	2.5
072-86-B1.119	M	35	Y	N	spicules	spicules	uneven	uneven	spicules	3
072-86-B1.123	F	66	O	N	uneven	uneven	-	uneven	spicules	-
072-86-B1.138	F	59.9	M	N	-	spicules	smooth	-	spicules	-
072-86-B1.144	F?	78	O	N	-	-	-	-	-	-
072-86-B1.148	M	50.5	M	N	2.1	spicules	-	-	spicules	-
072-86-B1.93	F	76.8	O	N	spicules	-	uneven	-	-	-
072-86-B2.50	M	34.6	Y	N	-	-	uneven	smooth	2.7	spicules
072-86-B2.57	F	61.3	O	N	-	spicules	uneven	smooth	spicules	-
072-86-B2.62	M	38.7	Y	N	-	-	smooth	smooth	spicules	spicules
072-86-B3.21	F	59.7	M	N	-	-	smooth	smooth	uneven	uneven
072-86-B3.59	M	37.3	Y	N	-	-	-	-	-	spicules
072-86-B3.67	F	34.3	Y	N	uneven	uneven	uneven	uneven	uneven	uneven
072-86-B3.87	M	30.5	Y	N	uneven	uneven	-	-	-	-
101-03-UF2	I	17.8	A	N	-	-	-	smooth	-	-
125-99-UF8	M?	A	A	N	smooth	smooth	-	uneven	spicules	spicules

Table 7.2 cont...

	139-02-UF3	I	34.2	Y	N	smooth	-	smooth	-	-	-
	139-02-UF7	F	42.7	M	N	-	-	-	3.8	-	-
	162-06-UF03	F?	47.2	M	N	smooth	-	1.7	2.8	3	spicules
	162-06-UF06	M	37.7	Y	N	-	smooth	-	-	-	-
	18-01-T1	M	A	A	N	-	smooth	spicules	-	-	-
	18-01-T15 (UE61)	M	35.2	Y	N	-	smooth	uneven	smooth	spicules	spicules
	18-01-T16	I	71.2	O	N	-	-	smooth	smooth	-	-
	18-01-T22	F	21.4	Y	N	-	smooth	spicules	spicules	-	uneven
	18-01-T25	M	36.6	Y	N	uneven	uneven	spicules	uneven	3.1	4.6
	18-01-T28	F?	26	Y	N	smooth	uneven	1.5	-	spicules	spicules
	18-01-T29	F	42.1	M	N	uneven	-	uneven	-	spicules	spicules
	201-05-UF1	F	51.2	M	N	smooth	-	-	-	-	-
	201-05-UF17	I	72.7	O	N	-	-	-	-	-	-
	201-05-UF18	I	15	A	N	-	-	-	-	-	-
	201-05-UF19	F	50.8	M	Poss Stage 2	smooth	smooth	2.4	3.6	-	-
	201-05-UF28	F	34.9	Y	N	uneven	-	smooth	-	spicules	-
	201-05-UF6	I	A	A	N	-	smooth	-	-	-	-
	311-04-UF1	F?	73.5	O	N	smooth	-	smooth	-	smooth	smooth
	615	I	A	A	N	smooth	smooth	-	-	-	-
	1035	F?	76.5	O	N	-	smooth	-	-	smooth	-
	1045	M	15	A	N	-	-	-	-	smooth	smooth
	1058	I	15	A	N	smooth	smooth	-	smooth	smooth	-
	1069	F	15	A	N	-	-	-	-	-	smooth
	1075	M	76.4	O	N	smooth	smooth	-	-	-	-
	1104	M?	20.5	Y	N	smooth	-	smooth	smooth	spicules	smooth
	1113	F	65.5	O	N	smooth	-	3.5	-	spicules	spicules
	1215	F	15	A	N	-	smooth	-	-	-	smooth
Tarraco	1435	M	45.5	M	N	-	smooth	-	-	5.1	6.2
	1442	M	21.6	Y	N	smooth	smooth	-	-	-	-
	1726	M	A	A	Stage 1	-	5	-	-	-	-
	1731	F?	A	A	N	-	-	-	-	-	-
	2032 (UF2A)	M	74.3	O	N	-	-	-	smooth	-	-
	2102	M	76.5	O	N	spicules	spicules	spicules	spicules	-	-
	2192	M	67.2	O	Poss Stage 2	3.3	-	-	-	-	-
	2226	M	77.3	O	N	spicules	spicules	-	-	-	-
	2230	I	15	A	N	smooth	smooth	-	-	smooth	smooth
	2413	M	72.6	O	N	smooth	smooth	-	-	-	smooth

Table 7.2 cont...

Site	Ind.	Sex	Age (95%)	Y/M/O	DISH	R olec.	L olec.	R pat.	L pat.	R calc.	L calc.
	5395	I	15	A	N	uneven	-	-	-	4.7	uneven
	(UF5)	I	24.9	Y	N	smooth	-	-	-	-	-
	UF01A	M	16.6	A	N	smooth	-	-	-	-	-
	UF01B	M	23.7	Y	N	-	-	-	spicules	spicules	2.6

7.3 Individuals from the early medieval English site of Raunds

						Extra-spinal enthesopathies (mm.)					
Site	**Ind.**	**Sex**	**Age (95%)**	**Y/M/O**	**DISH**	**R olec.**	**L olec.**	**R pat.**	**L pat.**	**R calc.**	**L calc.**
Raunds	5002	M	16.6	A	N	spicules	spicules	smooth	smooth	uneven	smooth
	5003	M	26.5	Y	N	smooth	smooth	smooth	smooth	spicules	-
	5006	M	72.5	O	N	smooth	smooth	smooth	-	-	2.1
	5007	M	70	O	N	smooth	smooth	-	uneven	uneven	uneven
	5008	F	81.7	O	N	smooth	smooth	2.6	2.5	4.3	3.1
	5009	M	35	Y	Poss Stage 2	-	-	1.6	1.6	2.4	spicules
	5010	M	73.4	O	N	smooth	smooth	spicules	uneven	4.5	-
	5016	M	31.5	Y	N	-	-	smooth	smooth	uneven	spicules
	5017	F	12	A	N	smooth	smooth	smooth	-	smooth	smooth
	5018	F	20.2	Y	N	smooth	smooth	smooth	smooth	smooth	smooth
	5019	F	75.1	O	N	smooth	uneven	spicules	spicules	spicules	3.1
	5020	I	38.3	Y	N	smooth	smooth	smooth	smooth	smooth	spicules
	5021	F	42.8	M	N	smooth	smooth	smooth	smooth	spicules	spicules
	5022	M	21.1	Y	N	smooth	2.1	2.6	spicules	smooth	smooth
	5024	M	61.7	O	N	smooth	spicules	2.7	2.1	-	5
	5025	M?	71.9	O	N	-	-	smooth	-	-	2.1
	5026	M	35.8	Y	N	smooth	smooth	2.1	spicules	spicules	spicules
	5028	F	23.5	Y	N	smooth	smooth	smooth	smooth	uneven	uneven
	5031	F	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
	5035	F	75.4	O	N	1.7	2	1.7	1.7	3.6	2.9
	5036	F	45	M	N	smooth	smooth	spicules	spicules	uneven	uneven
	5039	I	A	A	N	-	-	-	-	-	-
	5042	F	22.7	Y	N	smooth	smooth	-	-	uneven	uneven
	5045	F	79.6	O	Poss Stage 1	smooth	smooth	smooth	smooth	5.9	6.5

Table 7.3 cont...

5046	M	19.2	A	N	smooth	smooth	smooth	-	-	uneven
5047	I	29.3	Y	N	smooth	uneven	smooth	-	-	-
5048	F?	29.1	Y	N	smooth	smooth	uneven	smooth	smooth	spicules
5049	F	34	Y	N	smooth	smooth	spicules	spicules	spicules	spicules
5050	F?	71.8	O	N	-	smooth	-	7.4	-	-
5051	F	51.3	M	N	smooth	smooth	smooth	smooth	spicules	spicules
5052	F	27.6	Y	N	smooth	smooth	2.8	spicules	-	-
5054	M	27.4	Y	N	uneven	uneven	uneven	smooth	spicules	uneven
5055	M	46.5	M	N	spicules	uneven	25	2.3	5.8	4.6
5056	F	15	A	N	uneven	uneven	uneven	uneven	uneven	spicules
5061	F	49.3	M	N	spicules	spicules	-	smooth	7.1	4.3
5062	I	A	A	Poss Stage 1	spicules	-	8.4	6.1	4.1	8
5064	M	65	O	N	smooth	smooth	smooth	smooth	spicules	spicules
5071	U	60.5	O	N	smooth	smooth	smooth	smooth	-	-
5074	M	29.7	Y	N	smooth	smooth	3.7	5.8	4.6	spicules
5076	F	31.8	Y	N	smooth	smooth	spicules	smooth	spicules	1.8
5085	M	37.8	Y	Stage 2	smooth	smooth	3.3	2.3	4.8	1.7
5087	F	33	Y	Stage 2	-	2	spicules	4.8	6	6.2
5092	F	75.8	O	N	smooth	smooth	smooth	smooth	6.6	-
5095	M	15	A	N	smooth	-	smooth	smooth	smooth	-
5098	M	54.6	M	Poss Stage 2	7.6	smooth	-	uneven	spicules	smooth
5099	F	28.1	Y	N	smooth	smooth	smooth	uneven	spicules	spicules
5100	F	65.3	O	N	smooth	smooth	-	smooth	2.8	spicules
5103	F?	24.6	Y	N	smooth	smooth	-	-	3.6	-
5106	F	66.5	O	N	smooth	smooth	-	smooth	3.1	5
5107	M	15	A	N	smooth	-	smooth	smooth	smooth	smooth
5112	M?	30.9	Y	N	smooth	smooth	-	smooth	32	-
5118	M	45.5	M	Stage 2	smooth	smooth	smooth	spicules	-	uneven
5119	F	A	A	Poss Stage 1	-	-	-	-	-	-
5120	M	74.8	O	Stage 2	-	spicules	8.3	8.3	-	-
5122	F	15.2	A	N	-	-	smooth	-	-	smooth
5124	I	32	Y	N	uneven	smooth	spicules	spicules	spicules	spicules

Table 7.3 cont...

5129	M	25.7	Y	N	smooth	smooth	-	-	spicules	-
5133	M	76.3	O	Poss Stage 1	smooth	smooth	-	uneven	-	spicules
5136	M	79.7	O	N	3.2	5.5	spicules	3.8	3.7	spicules
5139	F	41.9	M	N	uneven	uneven	-	-	-	-
5142	F	15.4	A	N	smooth	smooth	-	smooth	spicules	spicules
5145	F	46.8	M	N	smooth	-	2.4	spicules	-	spicules
5147	M?	77.8	O	N	2.3	spicules	spicules	spicules	-	-
5150	F	36	Y	Poss Stage 1	uneven	uneven	spicules	2.1	3.5	26
5153	M	74.1	O	Poss Stage 1	uneven	smooth	spicules	-	5.4	7.8
5154	F	19	A	N	smooth	smooth	smooth	smooth	spicules	spicules
5155	M	33.5	Y	Stage 2	8	2.7	6.9	6.7	2.8	4.5
5156	M?	70.6	O	N	uneven	uneven	spicules	5.1	-	-
5159	F	71.1	O	N	uneven	uneven	3.6	8.3	2.5	-
5160	F	73	O	N	smooth	spicules	uneven	uneven	spicules	-
5161	F	77.1	O	N	uneven	smooth	uneven	spicules	uneven	spicules
5166	I	32.2	Y	N	spicules	2.1	5.1	-	2.4	4
5167	F	46	M	N	smooth	-	spicules	spicules	1.4	2.9
5180	F	22.3	Y	N	uneven	smooth	smooth	smooth	-	smooth
5181	F	23	Y	N	smooth	smooth	spicules	uneven	4.1	uneven
5183	M	30.9	Y	N	smooth	smooth	2.2	4	-	-
5184	M	26.9	Y	N	smooth	-	uneven	smooth	smooth	smooth
5186	M	84.2	O	Stage 2	spicules	spicules	spicules	4.2	spicules	spicules
5187	F	16.7	A	N	uneven	spicules	-	-	-	spicules
5197	M	42	M	N	uneven	uneven	-	-	-	3.1
5202	M	19.5	A	N	uneven	-	-	2.9	-	2.9
5203	M	35.6	Y	Stage 1	smooth	uneven	uneven	uneven	-	-
5207	F	44	M	N	uneven	uneven	smooth	smooth	spicules	spicules
5211	F	32.7	Y	N	uneven	uneven	uneven	uneven	-	-
5214	F	71.6	O	N	uneven	spicules	smooth	smooth	spicules	uneven
5217	F	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
5218	M	34.4	Y	N	smooth	uneven	-	uneven	-	spicules
5219	M	25.6	Y	N	smooth	smooth	-	smooth	smooth	uneven

Table 7.3 cont...

5220	F	31. 1	Y	N	smooth	-	spicules	smooth	3.7	spicules
5221	F	23.7	Y	N	smooth	smooth	smooth	smooth	uneven	spicules
5224	F	76.6	O	N	spicules	1.4	spicules	spicules	3.2	2.5
5228	F	71.3	O	N	-	-	smooth	smooth	2.1	-
5229	M	73.6	O	N	-	spicules	spicules	uneven	spicules	spicules
5230	F	35	Y	N	smooth	smooth	-	-	spicules	spicules
5232	F	57.2	M	N	smooth	smooth	spicules	spicules	spicules	spicules
5236	F	76.2	O	N	smooth	uneven	smooth	smooth	uneven	uneven
5237	F	15	A	N	smooth	smooth	smooth	smooth	uneven	smooth
5239	F	34.4	Y	N	4.2	4.2	spicules	-	3.2	4.7
5241	F	22.6	Y	N	spicules	uneven	spicules	spicules	-	-
5242	M	65.3	O	N	uneven	smooth	spicules	-	spicules	1.5
5247	F	45.8	M	N	spicules	spicules	smooth	spicules	3.8	5
5250	F	15	A	N	smooth	smooth	-	-	spicules	1.7
5252	F	69.1	O	N	uneven	uneven	uneven	uneven	spicules	spicules
5257	F	74.1	O	Poss Stage 2	uneven	uneven	-	smooth	spicules	spicules
5266	F	15	A	N	smooth	smooth	uneven	-	smooth	smooth
5282	M	68.5	O	Stage 3	smooth	smooth	8.5	spicules	5.7	6.6
5285	M	68	O	N	spicules	smooth	spicules	spicules	-	5.1
5286	M	76.7	O	N	smooth	uneven	3.9	4.8	4.6	-
5298	F	79.7	O	Stage 2	spicules	spicules	uneven	uneven	-	-
5314	I	19	A	N	-	spicules	smooth	smooth	3.3	5.6
5321	M	65.9	O	N	uneven	uneven	smooth	uneven	-	-
5363	M	37.4	Y	N	uneven	uneven	uneven	uneven	2.6	spicules
5371	F	15	A	N	uneven	smooth	spicules	spicules	smooth	smooth
5094a	M	65.1	O	Stage 2	smooth	-	spicules	smooth	uneven	spicules
5094b	F	47.9	M	N	uneven	smooth	1.9	-	-	-

7.4 Individuals from the early medieval Catalan sites of Sant Esteve de Granollers and Sant Pere de Terrassa

Site	Ind.	Sex	Age (95%)	Y/M/O	DISH	Extra-spinal enthesopathies (mm.)					
						R olec.	L olec.	R pat.	L pat.	R calc.	L calc.
Sant Esteve de Granollers	9	F	37.5	Y	N	-	smooth	smooth	uneven	uneven	uneven
	57	F	15	A	N	-	smooth	smooth	smooth	smooth	smooth
	60	F	24.2	Y	N	smooth	smooth	smooth	smooth	smooth	smooth
	61	F	36.8	Y	N	smooth	smooth	-	smooth	2.2	2.3
	72	M	73.4	O	N	uneven	uneven	-	-	-	-
	76	F	52.4	M	N	-	-	uneven	uneven	spicules	spicules
	88	F	28.6	Y	N	smooth	smooth	uneven	smooth	uneven	uneven
	96	F	19.8	A	N	uneven	uneven	uneven	-	smooth	uneven
	98	F	31.2	Y	N	uneven	uneven	2.4	-	spicules	spicules
	1074	M	79.9	O	N	smooth	-	-	-	-	-
	1280	M	69	O	N	smooth	smooth	-	-	-	-
	1318	F	43.4	M	N	uneven	uneven	-	-	-	-
	1625	M	25.3	Y	N	smooth	-	-	-	-	-
	1704	F	28.8	Y	N	uneven	-	-	-	spicules	1.5
	2072	M	66	O	N	smooth	-	spicules	spicules	spicules	spicules
	2156	M	67.1	O	N	-	-	-	-	4.7	2.2
	2187	I	57.5	M	N	smooth	-	-	-	-	-
	2326	M	70.8	O	N	uneven	uneven	uneven	2.1	5.6	5.8
Sant Pere de Terrassa	6	M	20.1	Y	Poss Stage 1	smooth	smooth	uneven	uneven	smooth	smooth
	10	F	34.8	Y	N	smooth	smooth	uneven	uneven	-	-
	30	M	39	Y	N	uneven	uneven	uneven	-	-	4.3
	40	F	71.8	O	N	smooth	smooth	smooth	smooth	uneven	uneven
	49	M	74.1	O	N	smooth	smooth	1.8	-	-	-
	60	M	40.7	M	N	smooth	smooth	smooth	smooth	4.1	4.5
	94	F	47.7	M	N	-	-	3.1	3.8	spicules	4.3
	95	F	36.4	Y	N	-	smooth	smooth	smooth	smooth	smooth
	203	M	77.9	O	N	smooth	uneven	uneven	uneven	-	-
	259	M	75.4	O	N	-	-	spicules	uneven	-	-
	278	F	51.5	M	N	smooth	smooth	4.4	3	6.5	4.5

Table 7.4 cont...

281	F	71.1	O	N	-	-	uneven	uneven	spicules	2
329	M	68.4	O	N	smooth	-	spicules	smooth	-	-
345	M	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
365	M	35.2	Y	Stage 2	smooth	smooth	smooth	smooth	1.9	1.2
368	M	75.5	O	N	spicules	smooth	smooth	spicules	5.3	5.1
388	F	35.6	Y	N	-	smooth	-	smooth	-	smooth
394	I	60.3	O	N	smooth	smooth	smooth	-	smooth	smooth
395	F	32.9	Y	N	smooth	-	-	smooth	-	smooth
405	F	47.4	M	N	smooth	-	1.8	smooth	4.8	3.6
415	M	27.1	Y	N	smooth	smooth	smooth	smooth	uneven	uneven
425	M	38.9	Y	N	smooth	smooth	-	-	spicules	-
432	F	15	A	N	uneven	-	smooth	smooth	-	spicules
480	F	80	O	Stage 4	smooth	smooth	4.4	5.3	spicules	3.9
533	F	39.2	Y	N	smooth	smooth	-	-	-	-
559	F?	29.5	Y	N	smooth	smooth	5.8	5.8	uneven	uneven
635	F	62.4	O	N	smooth	-	smooth	-	spicules	3.1
655	M	15.6	A	N	smooth	smooth	uneven	smooth	-	-
658	M	49.9	M	Stage 2	-	-	spicules	spicules	4.2	5.8
670	F	33.3	Y	Poss Stage 1	uneven	uneven	3.8	5.4	spicules	3
672	M	41.5	M	N	smooth	-	uneven	uneven	spicules	spicules
679	F	15	A	N	-	-	smooth	smooth	smooth	smooth
680	M	23.7	Y	N	smooth	smooth	smooth	-	spicules	spicules
682	F	26.3	Y	N	smooth	smooth	smooth	smooth	smooth	smooth
690	I	77.9	O	N	smooth	smooth	2	-	-	-
695.2	M?	75.4	O	N	-	smooth	-	6.1	spicules	spicules
697	I	72	O	Poss Stage 1	smooth	-	-	spicules	3	-
704	M	27.3	Y	N	spicules	spicules	smooth	1.3	6.2	3.9
712	F	77.3	O	N	-	-	1.7	smooth	spicules	4
713	M	72.3	O	Stage 3-4	spicules	-	spicules	spicules	2.9	3
753	F	31.4	Y	N	uneven	-	7.1	-	3.2	3.1
755	F?	71.9	O	N	smooth	smooth	-	-	-	-
769	M	20.4	Y	N	-	uneven	-	-	2.2	spicules
771	M	73.6	O	N	smooth	smooth	-	-	4.7	4.4

Table 7.4 cont...

	774	I	71.2	O	Stage 1	uneven	spicules	smooth	uneven	2.1	4
	775	M	26.1	Y	N	smooth	smooth	spicules	spicules	1.8	2.8
	778	F	15	A	N	-	smooth	smooth	smooth	-	smooth

7.5 Individuals from the late medieval English site of York Fishergate House

Site	Ind.	Sex	Age (95%)	Y/M/O	DISH	Extra-spinal enthesopathies (mm.)					
						R olec.	L olec.	R pat.	L pat.	R calc.	L calc.
York Fishergate House	13	M	67.4	O	N	uneven	3	2.3	spicules	spicules	spicules
	21	F	41	M	N	uneven	3.2	-	-	-	-
	27	F	68,3	O	N	uneven	uneven	-	-	-	-
	28	M	36.3	Y	Stage 4	7.6	8.5	spicules	-	-	5.2
	29	F?	27.4	Y	N	-	uneven	-	-	-	-
	30	F	19.9	A	N	smooth	smooth	smooth	-	uneven	uneven
	31	F	29.8	Y	N	uneven	uneven	2.8	4.6	3.9	4.8
	39	F?	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
	40	M?	80	O	N	uneven	smooth	2.4	4.3	spicules	spicules
	43	M	76.5	O	N	spicules	-	-	smooth	spicules	spicules
	44	M	21.3	Y	N	smooth	smooth	uneven	2.1	uneven	uneven
	48	F	54.6	M	N	smooth	smooth	-	-	-	-
	49	F	41.7	M	N	uneven	-	-	smooth	uneven	uneven
	50	F	75.9	O	N	uneven	-	uneven	-	uneven	uneven
	52	F	59.9	M	N	smooth	smooth	smooth	-	uneven	uneven
	57	M	15	A	N	-	smooth	smooth	-	smooth	smooth
	58	F?	73.8	O	N	-	uneven	spicules	spicules	spicules	spicules
	60	M	62.5	O	N	uneven	uneven	uneven	uneven	uneven	uneven
	61	F	27.7	Y	N	smooth	smooth	-	smooth	-	spicules
	62	M	81.5	O	Stage 2	5.3	uneven	-	-	3.6	3.2
	67	F	20.6	Y	N	uneven	smooth	uneven	smooth	smooth	smooth
	68	M	74.4	O	N	uneven	uneven	-	uneven	spicules	spicules

Table 7.5 cont...

73	M	72.9	O	N	2.8	4.1	8.4	9.4	9	5.8
76	F	31,5	Y	N	-	smooth	-	-	-	-
77	M	83.7	O	N	spicules	uneven	spicules	spicules	-	-
82	F	39.2	Y	N	-	-	-	-	-	-
84	F	50.4	M	Poss Stage 2	spicules	spicules	-	-	-	-
86	M	86.2	O	N	1.9	uneven	2.5	1.8	uneven	spicules
87	F	23	Y	N	uneven	uneven	smooth	uneven	spicules	spicules
90	M	52.9	M	N	spicules	spicules	2.1	-	4.1	2.5
92	I	A	A	Stage 2	-	-	-	-	-	-
94	F	38.9	Y	N	smooth	smooth	-	-	-	-
96	M	38.4	Y	N	-	-	4.9	spicules	5.6	4.3
98	F	79.1	O	N	3.7	spicules	3	2.1	spicules	uneven
101	M	35.4	Y	N	uneven	uneven	spicules	spicules	spicules	2.6
110	F	54.1	M	N	-	uneven	-	-	spicules	uneven
113	F	42.9	M	N	uneven	spicules	uneven	-	spicules	spicules
120	M	75.4	O	Stage 4	spicules	spicules	spicules	spicules	3.8	spicules
130	F	43.3	M	N	spicules	uneven	spicules	spicules	4.3	2.3
131	F	49.5	M	N	smooth	-	2,5	-	-	-
136	M	36.3	Y	N	uneven	1.4	2.9	4.2	1.8	2.2
149	F	37.5	Y	Poss Stage 1	1.4	uneven	-	-	3.6	5.3
155	F	37.4	Y	N	uneven	uneven	uneven	uneven	uneven	spicules
159	F	55.3	M	N	1.7	4.9	2.4	3.3	-	-
163	F	23.7	Y	N	uneven	uneven	uneven	uneven	spicules	spicules
168	F	15	A	N	smooth	-	smooth	smooth	smooth	-
172	M	29.2	Y	Stage 2	-	-	-	-	-	-
173	F	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
175	I	80.7	O	N	spicules	spicules	spicules	spicules	2.8	3.9
186	M	33.6	Y	N	-	uneven	-	smooth	-	-
204	M	76	O	N	uneven	spicules	uneven	uneven	spicules	3.2
209	M	17	A	N	smooth	-	smooth	uneven	uneven	uneven
219	M	62.3	O	N	uneven	spicules	-	-	-	spicules
251	F	78.3	O	N	-	spicules	7.4	3.2	-	spicules

Table 7.5 cont...

	259	F	70.8	O	N	2.4	3.4	8	uneven	spicules	spicules
	260	M	66.2	O	N	-	so	-	-	spicules	spicules
	261	M	29	Y	N	-	-	smooth	-	-	-
	279	F	56.9	M	N	smooth	smooth	smooth	-	spicules	spicules
	292	M	40.1	M	N	smooth	smooth	-	-	-	-
	296	M	30.4	Y	N	smooth	-	-	smooth	spicules	spicules
	308	F	70.5	O	Stage 4	2.6	2.4	6.2	3.9	4.5	spicules
	309	M	71.2	O	N	-	-	smooth	smooh	spicules	spicules
	310	M	85	O	N	uneven	uneven	uneven	uneven	4.9	3.5
	317	F	55.2	M	N	-	-	-	-	spicules	spicules

7.6 Individuals from the late medieval Catalan sites of Sant Esteve de Canapost, Sant Miquel d'Olèrdola, Sant Pere de Terrassa and Vila-Sacra

						Extra-spinal enthesopathies					
Site	**Ind.**	**Sex**	**Age (95%)**	**Y/M/O**	**DISH**	**R olec.**	**L olec.**	**R pat.**	**L pat.**	**R calc.**	**L calc.**
Sant Esteve de Canapost	60	I	68.4	O	N	-	-	-	uneven	-	-
	61	I	A	A	N	-	-	-	-	-	-
	68	F?	62	O	N	spicules	-	-	-	-	-
	69	F?	53.2	M	N	uneven	-	-	-	1.8	spicules
	79	F	66.8	O	N	-	uneven	uneven	uneven	-	-
	87	F	21.7	Y	N	smooth	uneven	-	smooth	uneven	uneven
	95	F	28.4	Y	N	smooth	smooth	spicules	spicules	-	-
	99	I	15	A	N	smooth	smooth	smooth	smooth	smooth	smooth
	140	M	73.3	O	N	spicules	-	uneven	uneven	-	-
	170	M	31	Y	N	smooth	-	uneven	uneven	spicules	uneven
	176	F	73.3	O	N	smooth	smooth	-	-	-	spicules
	193	M?	77.7	O	N	-	uneven	spicules	uneven	spicules	spicules
	194	M?	76.8	O	N	uneven	uneven	spicules	spicules	spicules	spicules
	197	F	20.5	Y	N	smooth	smooth	smooth	smooth	smooth	smooth
	212	F?	15	A	N	uneven	uneven	smooth	smooth	uneven	uneven
	213	M?	70.3	O	N	uneven	uneven	smooth	-	uneven	uneven

Table 7.6 cont...

	214	M	75.9	O	N	spicules	smooth	-	-	-	-
	206	F	74.6	O	N	smooth	smooth	-	-	-	-
	224	I	43.3	M	N	smooth	uneven	smooth	smooth	spicules	spicules
	228	F?	38.5	Y	N	smooth	-	-	-	spicules	spicules
	230	F?	A	A	N	smooth	smooth	smooth	-	-	-
	237	F	43.1	M	N	uneven	uneven	uneven	uneven	2.5	2.5
	242	I	A	A	N	uneven	uneven	uneven	-	spicules	spicules
	265	F?	65.2	O	N	-	uneven	-	-	-	-
	270	F	76.9	O	N	uneven	uneven	smooth	-	-	-
	271	F?	49.9	M	N	-	-	-	-	-	-
	274	M	79.3	O	Poss Stage 1	uneven	uneven	-	-	spicules	spicules
	279	M	23	Y	Stage 3	smooth	smooth	smooth	smooth	4	2.7
	276	I	66.9	O	N	uneven	uneven	-	-	-	-
	286	F	79.9	O	N	smooth	smooth	spicules	uneven	5.4	4.5
	297	I	83.6	O	N	spicules	spicules	-	-	spicules	spicules
	1054	M	34.1	Y	N	-	-	-	-	-	-
Sant Miquel d'Olèrdola	10	F	43.6	M	n	uneven	-	-	uneven	2.5	1.6
	18	M	36.1	Y	n	uneven	uneven	spicules	spicules	spicules	-
	27	M	38	Y	n	-	-	spicules	spicules	uneven	spicules
	38a	I	A	A	n	smooth	-	-	-	-	-
	44	F	68	O	n	uneven	uneven	-	-	3.4	4
	59	I	43.8	M	n	-	-	-	-	-	-
	67	M	15	A	n	-	-	smooth	uneven	uneven	-
	68	M	77	O	Poss 2	smooth	uneven	uneven	uneven	spicules	spicules
	72	F	15	A	n	-	uneven	-	smooth	-	-
	73	M	66.8	O	n	-	-	-	4	-	-
Sant Pere de Terrassa	228	F	A	A	n	smooth	smooth	uneven	uneven	-	-
	288	I	A	A	Poss 1	smooth	smooth	2.3	spicules	2.5	spicules
	261	I	A	A	n	smooth	smooth	smooth	smooth	uneven	uneven
	265	F	34.5	Y	n	smooth	smooth	smooth	smooth	-	-
	611	M	41.1	M	n	smooth	smooth	spicuels	-	uneven	uneven
	612	I	67.7	O	n	smooth	-	-	smooth	spicules	-
	613	F	80.5	O	n	uneven	smooth	3.5	1.6	spicules	spicules
	619	M	78.7	O	Stage 2	-	smooth	4.4	-	5.8	5

Table 7.6 cont...

	627	M	15	A	n	smooth	smooth	smooth	-	smooth	smooth
	632	M	78	O	Stage 2	-	smooth	smooth	32	smooth	uneven
	660	M	42.9	M	n	smooth	smooth	-	-	-	-
	685	M	81.1	O	n	smooth	uneven	3.6	-	-	-
	756	F	24	Y	n	uneven	-	smooth	smooth	smooth	unever
	770	F	73.8	O	n	smooth	smooth	-	-	-	smootl
Vila-Sacra	6	M?	A	A	N	-	smooth	-	-	-	-
	8	M	61	O	N	uneven	uneven	uneven	uneven	3.6	3.3
	16	F	31	Y	N	smooth	-	-	-	-	spicules
	18	F?	62.3	O	N	-	-	-	spicules	-	-
	19	I	A	A	N	-	-	-	-	-	-
	34	I	A	A	N	-	smooth	-	-	-	-
	35	I	53.6	M	N	uneven	uneven	-	-	-	-
	38	I	27.3	Y	N	-	-	spicules	-	spicules	spicules
	44	M	20.2	Y	N	smooth	smooth	-	-	-	-
	52	M	78.6	O	N	uneven	uneven	-	-	-	-
	53	F?	55.2	M	N	smooth	-	-	-	-	-
	54	F	17.3	A	N	-	smooth	-	uneven	uneven	uneven
	63	M	62.5	O	N	spicules	-	smooth	-	spicules	spicules
	66	F	68.3	O	Poss 3	uneven	smooth	-	uneven	-	smooth
	68	F	62.5	O	N	uneven	so	smooth	smooth	spicules	spicules
	77	I	29.6	Y	N	-	-	-	-	-	-
	80	F	23.7	Y	N	smooth	smooth	-	uneven	spicules	spicules
	84	M	80.1	O	N	spicules	2.7	uneven	uneven	-	-
	85	I	76.5	O	N	uneven	smooth	-	-	-	-
	89	M	A	A	N	-	-	-	-	-	-
	90	M?	64	O	N	-	-	uneven	-	3.1	3.5
	91	F	16.3	A	N	smooth	smooth	uneven	-	uneven	uneven
	92	F	81.3	O	N	smooth	-	spicules	spicules	spicules	spicules
	96	M	77.3	O	N	-	-	-	-	-	-
	98	F	15.8	A	N	smooth	smooth	uneven	uneven	spicules	spicules
	99	I	53.5	M	Stage 3	spicules	-	uneven	spicules	spicules	spicules
	100	F	47.8	M	N	smooth	smooth	uneven	smooth	uneven	uneven

Table 7.6 cont...

104	F	26.8	Y	N	uneven	uneven	-	-	-	-
106	F	15	A	N	smooth	uneven	-	-	-	-
107	F	33.6	Y	N	smooth	smooth	uneven	uneven	uneven	spicule
109	M	15.3	A	N	smooth	smooth	-	smooth	smooth	smootl
115	F	34.9	Y	N	uneven	uneven	uneven	uneven	uneven	-
138	F	28.2	Y	N	2.5	3	uneven	-	4.4	spicule

7.7 Individuals from the post-medieval English site of Wolverhampton

Site	Ind.	Sex	Age (95%)	Y/M/O	DISH	Extra-spinal enthesopathies (mm.)					
						R olec.	L olec.	R pat.	L pat.	R calc.	L calc.
	HB109	F	21.3	Y	N	-	-	uneven	smooth	-	-
	HB111	F	27.6	Y	N	smooth	uneven	smooth	smooth	spicules	spicules
	HB116	F	30.2	Y	N	uneven	smooth	-	smooth	-	-
	HB117	M	61.6	O	N	2	spicules	smooth	smooth	-	-
	HB118	F	15	A	N	smooth	smooth	smooth	smooth	-	-
	HB124	M	A	A	N	spicules	uneven	-	-	-	-
	HB125	F	15	A	N	smooth	smooth	-	smooth	-	-
	HB128	F	31.7	Y	N	-	uneven	-	2.2	-	-
	HB28	F	19.4	Y	N	uneven	smooth	uneven	smooth	-	-
	HB35	F	20.8	Y	N	uneven	uneven	-	-	-	-
Wolverhampton	HB36	M	73.5	O	Poss Stage 1	4.5	spicules	spicules	uneven	spicules	spicules
	HB39	F?	73.3	O	Stage 4	3.4	-	-	-	-	-
	HB43	M	73.5	O	N	-	5.9	-	-	-	-
	HB44	I	28.9	Y	N	uneven	spicules	spicules	uneven	-	-
	HB46	M	49.5	M	N	smooth	smooth	smooth	smooth	-	-
	HB53	F	31.7	Y	N	smooth	-	-	-	-	-
	HB54	F	64.5	O	N	spicules	-	-	-	-	-
	HB56	M	67.1	O	N	spicules	smooth	uneven	smooth	2.5	spicules
	HB61	F	32.3	Y	N	smooth	uneven	-	-	-	-
	HB62	F	33.1	Y	N	-	-	-	smooth	-	-
	HB70	F	59.9	M	N	smooth	smooth	-	smooth	smooth	smooth

Table 7.7 cont...

			53.9	M	N	uneven	-	uneven	smooth	-	-
	HB88	F	25.6	Y	N	-	smooth	-	-	-	-
	HB90	F	66.2	O	N	smooth	-	-	smooth	-	-
	HB96	M	72	O	N	spicules	uneven	-	-	-	-
	HB97	U	A	A	N	-	smooth	-	-	-	-
	HB98	F	40.1	M	N	smooth	smooth	-	uneven	-	uneven

7.8 Individuals from the post-medieval Catalan site of Sant Esteve de Canapost

						Extra-spinal enthesopathies (mm.)					
Site	**Ind.**	**Sex**	**Age (95%)**	**Y/M/O**	**DISH**	**R olec.**	**L olec.**	**R pat.**	**L pat.**	**R calc.**	**L calc.**
Sant Esteve de Canapost	7	77.9	M	O	N	-	spicules	uneven	-	4.3	-
	38	85.3	M	O	N	-	smooth	-	2.7	3.3	5.5
	44	75.6	I	O	N	-	-	-	-	spicules	-
	58	17.9	M	Y	N	uneven	smooth	smooth	uneven	uneven	uneven
	73	77.9	M	O	N	smooth	smooth	uneven	u	5.4	3.7
	102	77	M?	O	N	-	-	-	-	-	-

7.9 Relationship age – Stage of DISH development

Sample: Romano-British sample (Total sample=74, DISH=7)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	0	0	0	0
Middle adult	1	1	0	0
Old adult	0	2	0	3
Adult	0	0	0	0

Sample: Roman Catalan samples (Total sample=87; DISH=6)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	0	0	0	0
Middle adult	0	1	0	0
Old adult	2	2	0	0
Adult	1	0	0	0

Sample: Early medieval English (Total sample=116, DISH=19)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	2	4	0	0
Middle adult	0	2	0	0
Old adult	3	5	1	0
Adult	2	0	0	0

Sample: Early medieval Catalan (Total sample=65; DISH=8)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	2	1	0	0
Middle adult	0	1	0	0
Old adult	2	0	1	1
Adult	0	0	0	0

Sample: Late medieval English (Total sample=64; DISH=8)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	1	1	0	1
Middle adult	0	1	0	0
Old adult	0	1	0	2
Adult	0	1	0	0

Sample: Late medieval Catalan (Total sample=89; DISH=8)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	0	0	1	0
Middle adult	0	0	1	0
Old adult	1	3	1	0
Adult	1	0	0	0

Sample: English samples combines (Total sample=281; DISH=36)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	3	5	0	1
Middle adult	1	4	0	0
Old adult	4	8	1	6
Adult	2	1	0	0

Sample: Catalan samples combined (Total sample=247; DISH=22)

	Stage 1	Stage 2	Stage 3	Stage 4
Young adult	2	1	1	0
Middle adult	0	2	1	0
Old adult	5	5	2	1
Adult	2	0	0	0

7.10 Relationship sex – Stage of DISH development

	DISH Stage	England (n=34)	Catalonia (n=18)
Female	1	4 (11.8)	2 (11.1)
	2	4 (11.8)	1 (5.6)
	3	0 (0.0)	1 (5.6)
	4	3 (8.8)	1 (5.6)
Male	1	5 (14.7)	4 (22.2)
	2	13 (38.2)	7 (38.9)
	3	1 (2.9)	2 (11.1)
	4	4 (11.8)	0 (0.0)

Legend for tables 7.11 to 7.18

N: no; N. obs : not observable; Prob: probable; Poss: possible

OA: osteoarthritis; CL: carious lesions; Osteom.: osteomalacia; LEH: linear enamel hypoplasia; Discarth: discarthrosis

R: right; L: left; Lat: lateral; Med: medial; ML: medio-lateral; AP: antero-posterior

C: cervical; T: thoracic, L: lumbar; Central T: T5-9, Low T: T10-12

7.11 Pathologies observed in the Roman-British individuals from Baldock, Gambier Parry Lodge and Kingsholm

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Baldock	Bal 1022	N	N	N	N	N. obs	N	N	N	N
	Bal 1028	N	N	N	N	N	Poss - ML bending tibiae	N	N	N
	Bal 1040	N	L-no; R-N. obs	N	2	N. obs	N	N	1	N
	Bal 1077	N	N. obs	N	N	Poss	Poss	N	N	Central T
	Bal 1090	N	L-no; R-N. obs	N	N	N	N	N	N	Low T and L5
	Bal 1107	N	N. obs	N. obs	N	N	N	N	N	N
	Bal 1174	N	N	N	N	N	N	N	N	N
	Bal 1203	N	N	N	N	N	N	N	N	N
	Bal 1237	N	R	R acetab.[a]	3	N. obs	Poss - ML bending tibiae	N	N	Low T and L
	Bal 1263	N	N. obs	N	N	N. obs	N	N	N. obs	N
	Bal 1281	N	L-no; R-N. obs	N	1	N	Poss - ML bending tibiae and L tibia	N	N. obs	T11-L5
	Bal 1319	N	R-no; L-N. obs	N	N	N	N	N	N	Low T and L
	Bal 1320	N	N. obs	N	3	N	N	N	N. obs	T11-12, L3-5
	Bal 1342	N	N. obs	N. obs	1	N	N. obs	N	N. obs	N
	Bal 1372	N	N	N	N	N	N	N	N	T9-10
	Bal 1391	N	N	N	N	N	N	N	N	Low T
	Bal 1446	N	N	N	N	N	N	N	N	Low T
	Bal 1447	N	L-no; R-N. obs	N	3	N	N	N	3	N
	Bal 1480	N	N. obs	N	5	N	N	N	N	N
	Bal 1487	N	N	N	1	N	N	N	2	T10-12 and L
	Bal 2602	N	R-no; L-N. obs	N	1	N	N	N	1	L
	Bal 3644	N	L-no; R-N. obs	N	N. obs	N. obs	N	N	N. obs	N
	Bal 883	N	N	N	1	N	Poss	N	N	L
	Bal F18 L10	N	N	N	N. obs	N	N	N	N	N
	Bal F466	N	N	L acetab.	N	N	Yes	N	1	L

Table 7.11 cont...

			R-no; L-N. obs	N	2	N	N	N	3	C and L
	Bal F557 L2	N	L-no; R-N. obs	N	N. obs	N. obs	N	N	N. obs	N
	Bal F610 L1	N	N	N	N	N	N	N	N	N
	Bal F644	N	L-no; R-N. obs	N	N. obs	N	N. obs	N	N. obs	L
	Bal F653	N	N. obs	N	2	N	N. obs	N. obs	1	N
	500	N	N. obs	N	N. obs	N. obs	N	N	N	T
	510	N	N. obs	N	N	N	N	N	N	N
	518	N	L-no; R-N. obs	N	4	Poss	N	N	N	T8-9
	520	N	N. obs	N	N. obs	N. obs	N	N	N. obs	T10
	524	N	N. obs	N	1	N. obs	N	N	3	N
	529	N	N. obs	N	N. obs	N. obs	N	N	N. obs	T9
	530	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
	533	N	N. obs	N. obs	1	N	N. obs	N	1	N
	536	N	L-no; R-N. obs	N	N. obs	N. obs	N	N	N. obs	Low L
	543	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	T12
Gambier Parry Lodge	545	N	R-no; L-N. obs	N	N	N	N	N	N	T9-11
	549	N	L-no; R-N. obs	N	1	N	N	N	N	T9-12, L4-5
	553	N	N	N	N. obs	N. obs	N	N	N. obs	N
	561	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
	567	N	L-no; R-N. obs	N. obs	N. obs	N. obs	N. obs	N	N. obs	T11-12
	568	N	N	N	N	N	N	N	1	N
	571	N	N. obs	N. obs	N. obs	N. obs	N. obs	N	N. obs	Low T
	572	N	N	N	1	N	Yes	N	2	T9-12
	577	N	N. obs	N	2	N	N	N	N	L2-5
	582	N	N	N	N. obs	N. obs	N	N	N. obs	N
	583	N	N	N	N	N	N	N	N	N
	585	N	N	N	N	N	N	N	N	N
	35K 10	N	N. obs	N	1	N	N	N	N	T9-12 and L4
Kingsholm	K112	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	N
	K154	N	N	N	N	N	N	N	2	N
	K166a	N	R-N. obs; L-no	N	1	N	N	N	N	N
	K208	N	N	N	2	N	N	N	N	N

Table 7.11 cont...

	K213	N	N	distal tibia	1	N	N	N	N	T9-12
	K215	N	R-no; L-N. obs	N	N	N	N	N	N	N
	K234	N	R-N. obs; L-no	Lat condyle L fem/tib	2	N	N	N	N	C and T
	K251	N	N	N	N. obs	N	N	N	N. obs	T
	K292	N	N	R/L fem-pat	N. obs	N	N	N	N. obs	all verts[a]
	K31	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
	K415	N	N	N	3	N	N. obs	N	N	N
	K54	N	N. obs	N	N. obs	N. obs	Poss	N	N. obs	N
	K92	N	N	N	4	N	N	N	N	T9-10, L4-5
	K96	N	N	N	N	N	N	N	N	N

[a] all verts: cervical, thoracic and lumbar vertebrae affected

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Baldock	Bal 1072	Poss 1	N	N	2	N	N	N	1	Low T and L
	Bal 2225	2	N. obs	N	N	N. obs	N	N	N. obs	N
	Bal 1374	2	N. obs	N	N	N	N	N	N	L2-5
	Bal 1049	2	L-no; R-N. obs	N	1	N	N	N	N	C6-7, T3,T4,T7,T9, L1-4
	Bal 1122	4	R-no; L-N. obs	N	N	N	N	N	N	N
	Bal F92	4	R-no; L-N. obs	L acetab.	N. obs	N	Yes	N	N. obs	T and L in verts w/ DISH
GPL[a]	525	4	N. obs	N	N. obs	N. obs	N	N	N. obs	N

[a]GPL: Gambier Parry Lodge

7.12 Pathologies observed in the Roman Catalan individuals from Santa Caterina and Tarraco

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthrosis
Santa Caterina	001-01-745	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	early T12, L3-4
	001-01-748	N	L-no; R-N. obs	N	2	N	Yes	N	N	L
	001-01-755	N	N. obs	N	2	N. obs	N. obs	N	N	Low T
	001-01-757	N	N. obs	N	N	N	N. obs	N	N	N
	001-01-758	N	L-no; R-N. obs	N	N	N. obs	N	N	2	T
	002-00-704	N	N. obs	N. obs	N	N. obs	N. obs	N	2	N
	002-00-706	N	N	N	N	N. obs	N	N	3	N
	002-00-707	N	N. obs	N	1	N	N	N	1	Central T and L4
	002-00-708	N	L-no; R-N. obs	N	N	N. obs	N	N	N	N
	002-00-709	N	N. obs	N	1	N	N	N	3	T8-12, L
	002-00-710	N	N. obs	N	N	N	N	N	3	N
	002-00-711	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	T11-12
	002-00-719	N	N	N	N	N	N	N	N	N
	002-00-721	N	N	N	N. obs	prob	N	N	N. obs	N
	002-00-725	N	N	N	N	N	Yes	N	3	N
	002-00-729	N	N. obs	N	2	N	N	N	2	C6-7, T10-L5
	002-00-731	N	N	N	1	N. obs	N	N	1	L5
	002-00-732	N	N	N	N	N. obs	N	N	N. obs	T12-L5
	002-00-733	N	N	N	N	N. obs	N	N	N	N
	010-04-T14	N	N. obs	N	N	N	N	N	N	N
	010-04-T15	N	N. obs	N. obs	N	N	N	N	1	Yes
	010-04-T18	N	N. obs	N	N	N	Poss	N	N	N
	010-04-T3	N	R-no; L-early	N	N	N	Poss	N	N	N
	010-04-T8	N	N	N	N	N	Poss	N	1	N
	024-04-UE1114	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
	072-84-Q4.90	N	N. obs	N	N	N. obs	N	N	2	N
	072-84-Q4.96	N	N	N	N. obs	N. obs	N	N	N. obs	N
	072-86-A1.124	N	R-no;L-N. obs	N	N. obs	N	N	N	N	N

Table 7.12 cont...

072-86-B1.119	N	L-no; R-N. obs	N	1	N	N	N	2	Central T
072-86-B1.123	N	N	N	1	N	Poss	N	N	N
072-86-B1.138	N	N	N	N	N	N	N	3	N
072-86-B1.144	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
072-86-B1.148	N	L-no; R-N. obs	N	N	N	Poss	N	1	N
072-86-B1.93	N	N. obs	N	2	N. obs	N	N	N	C and lower T
072-86-B2.50	N	N	N	N	N	N	N	3+	N
072-86-B2.57	N	N	N	N. obs	N	N	N	N. obs	T
072-86-B2.62	N	R-no;L-N. obs	N	1	N	N	N	N	Yes
072-86-B3.21	N	R-no;L-N. obs	N	1	N	Prob	N	3	N
072-86-B3.59	N	N	N	N	N	N	N	N	Low T and L
072-86-B3.67	N	N	N	2	N	N	N	5	N
072-86-B3.87	N	N. obs	N	N	N	N. obs	N	1	N
101-03-UF2	N	N	N	N. obs	N. obs	N	N	N. obs	N
125-99-UF8	N	N. obs	N	N	N. obs	N	N	N	N
139-02-UF3	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
139-02-UF7	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
162-06-UF03	N	L-no; R-N. obs	N	N	N. obs	N. obs	N	N	N
162-06-UF06	N	N. obs	N	1	N. obs	N. obs	N	N	N
18-01-T1	N	N. obs	N. obs	3	N. obs	N	N	N	N
18-01-T15 (UE61)	N	L-no; R-N. obs	N	1	N. obs	N	N	N	N
18-01-T16	N	L-no; R-N. obs	N	1	N. obs	N	N	N	N
18-01-T22	N	L-no; R-N. obs	N	N. obs	N. obs	Poss	N	N. obs	N
18-01-T25	N	R	N	3	N. obs	N	N	N	N
18-01-T28	N	N. obs	N	N	N	N	N	N. obs	N
18-01-T29	N	N	N	N	N. obs	N	N	1	N
201-05-UF1	N	N. obs	N	N. obs	N. obs	N	N	1	N
201-05-UF17	N	N. obs	N. obs	N	N. obs	N. obs	N. obs	N	N
201-05-UF18	N	R	N	N	N	N	N	N	N
201-05-UF28	N	N. obs	N	N	N. obs	N	N	N	N
201-05-UF6	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
2032 (UF2A)	N	N. obs	N. obs	N. obs	N	N. obs	N. obs	N. obs	N

Table 7.12 cont...

	311-04-UF1	N	R-no;L-N. obs	N	1	N. obs	N	N	3	N
Tarraco	UF01A	N	N. obs	N	1	N	Poss	N	N	N
	UF01B	N	L-no; R-N. obs	N	1	N	N	N	3+	N
	615	N	N	N	N	N	Poss	N	2	N
	1035	N	R-no; L-N. obs	N	1	N. obs	N	N	3	N
	1045	N	N	N	N	N	N	N	3+	N
	1058	N	R-no; L-N. obs	N	N	N	Prob	N	3+	N
	1069	N	L-no; R-N. obs	N	N	N. obs	N	N	N	N
	1075	N	N. obs	N	N	N. obs	N	N	N	N
	1104	N	N	N	2	N. obs	N. obs	N. obs	3	N
	1113	N	N	N	N	N	N	N	N	v. early at L
	1215	N	L-no; R-N. obs	N. obs	N	N	N	N	N	N
	1435	N	L-no; R-N. obs	N	N	N	N	N	2	Low T and L
	1442	N	N. obs	N	1	N	N	N	N	N
	1731	N	R-no; L-N. obs	N. obs	N	N. obs	N. obs	N. obs	N	N
	2102	N	N. obs	N	2	N	N	N	N	N
	2226	N	N. obs	N	1	N. obs	N. obs	N. obs	N	C6-7
	2230	N	N. obs	N	N	N	N	N	N	N
	2413	N	N	N	1	N	Yes	N. obs	3	N
	5395	N	N	N	N. obs	N. obs	N	N	N. obs	Low T
	(UF5)	N	L-no; R-N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N

Individuals with DISH

	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthrosis
Santa Caterina	001-01-754	Poss 1	N. obs	N	1	N. obs	N. obs	N	N	N
	002-00-727	Poss 1	R and L	N	N. obs	N	Yes	N	N. obs	N
	001-01-756	Poss 2	N. obs	N	N	N	N	N	1	T12 and L
	2192	Poss 2	R-no; L- N. obs	N	N	N	Poss	N	3+	N
	201-05-UF19	poss 2	L-no; R- N. obs	N	N	N. obs	N	N	N. obs	N
	1726	1	R-no; L- N. obs	N	N. obs	N. obs	N	N	N	L2-5

7.13 Pathologies observed in the early medieval English individuals from Raunds

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Raunds	5002	N	N	N	N	Prob	N	N	N	v early in T
	5003	N	yes L, poss R	N	2	N	N	N	2	C7 and Low T
	5006	N	N	N	N. obs	N. obs	N	N	N. obs	Low T
	5007	N	N	N	2	N. obs	N	N	N	N
	5008	N	N	N	2	Prob	N	N	N	C5-6, T8-9, L3-5
	5010	N	R-no;L-N. obs	N	N	N	N	N	N	Low L
	5016	N	N. obs	N	1	N	Yes	N	N. obs	Low T and L
	5017	N	N	N	N	N	N	N	N	Low T
	5018	N	N	N	2	N	N	N	N	N
	5019	N	N	N	2	Prob	N	N	N	[illegible]nd L
	5020	N	N	N	N	Poss	N	N	N	[illegible]
	5021	N	N	N	N	N	N	N	N	N
	5022	N	N	N	N	Yes	Yes	N	2	N
	5024	N	N. obs	N	1	N	N	N	N	N
	5025	N	N. obs	N	N	N	N. obs	N	N	N
	5026	N	N. obs	R MTT[a]	1	N	N	N	N	Low T and L
	5028	N	N	N	1	N	N	N	N	T9-12, L3-5
	5031	N	N	N	N	N	Poss	N	N	N
	5035	N	N	N	N	N	N	N	N	Low T and L
	5036	N	R-no;L-N. obs	N	N	N	N	N	N	Low T
	5039	N	N. obs	N	N. obs	N. obs	N. obs	N. obs	N. obs	Low T and L
	5042	N	N	N	N	N	N	N	N	N
	5046	N	N. obs	N	N	N	N	N	N	N
	5047	N	N. obs	N	N. obs	N. obs	N	N	N	centre-low T
	5048	N	L-no; R-N. obs	N	N. obs	N. obs	N	N	N. obs	T12-L4
	5049	N	N. obs	N	2	N	N	N	N	N
	5050	N	N. obs	N	N	N	N	N	N	all verts
	5051	N	N	N	3	N	N	N	N	T9-10, L4-5

Table 7.13 cont...

5052	N	N	N	N	N	N	N	1	N
5054	N	R-no;L-N. obs	N	1	N	N	N	N	T4-6, 10, 11
5055	N	N	N	3	N	N	N	N	Yes
5056	N	prob L	N	N	N	N	N	N	N
5061	N	N	N	2	N	N	N	N. obs	C5-7, T and L
5064	N	N	N	N	N	N. obs	N	N	N
5071	N	L-no; R-N. obs	R/L knee	N. obs	N. obs	N. obs	N	N	all verts
5074	N	R-no;L-N. obs	R knee	1	N	Poss	N	N	Low T and L
5076	N	R-no;L-N. obs	N	1	N	N	N	N	N
5092	N	N	N	1	N	N	N	N	L4-5
5095	N	R-no;L-N. obs	N	N	N	N	N	N	N
5099	N	poss R/L	R fem head	3	N	N	N	3+	T10-L3
5100	N	N	N	N. obs	N. obs	N	N	N. obs	N
5103	N	R-no;L-N. obs	N	2	N. obs	N	N	N	N
5106	N	N	N	N	N	N	N	N	L
5107	N	N	N	1	N	N	N	1	N
5112	N	N. obs	N	N	N. obs	N	N	N. obs	T10-12
5122	N	N	N	N	N	N	N	1	N
5124	N	N	N	1	N	N	N	N	N
5129	N	L-no; R-N. obs	N	2	N	N	N	2	T9
5136	N	N	N	3	N	N	N	N. obs	T6-L
5139	N	R-no;L-N. obs	N	N	N	N	N	N	N
5142	N	L-no; R-N. obs	N	N	Yes	N	N	1	N
5145	N	N	N	1	Poss	N	N	N	N
5147	N	N. obs	N	1	N	N	N	N	T
5154	N	L	N	N	N	N	N	1	N
5156	N	R-no;L-N. obs	N	N	N	N. obs	N	N	N
5159	N	no	N	N	N	N	N	1	T and L
5160	N	R-no;L-N. obs	N	4	N	N. obs	N	N	N
5161	N	N	R 1st MTT-phal. Joint[b]	1	N	N	N	N	L
5166	N	N	N	N	N	N	N	N	L

Table 7.13 cont...

5167	N	N	L 1st MTT-phal. joint	2	N	N	N	N. obs	Low T and L
5180	N	N	N	N	N	N	N	N	N
5181	N	N	N	N	N	N	N	N	N
5183	N	N	N	N	N	N	N	2	N
5184	N	N	N	2	N	N	N	N	L1-2
5187	N	N	N	N	N	N	N	N	N
5197	N	N. obs	N	N	N	N	N	N	L3-5
5202	N	L-no; R-N. obs	N	N	N	N	N	N	N
5207	N	N	N	1	N	N	N	3+	C5-7, T and L
5211	N	N. obs	N	N	N	N	N	N. obs	N
5214	N	N	N	N	N	N	N	N	N
5217	N	N	N	N	N	N	N	N	N
5218	N	L-no; R-N. obs	N	N	N	N	N	N	N
5219	N	N	N	1	N	N	N	3+	T12
5220	N	N	L fem-pat, L 1st MTT-phal joint	N. obs	N	N	N	N	Low T
5221	N	N	N	N	N	N	N	N	N
5224	N	R and L	N	N	N	N	N	N	Low T and L
5228	N	N	N	2	N	Poss	N	N	N
5229	N	N	N	N	N	N	N	1	Low T
5230	N	N	N	N	N	N	N	1	N
5232	N	N	N	N	N	N	N	3	C1, T12-L5
5236	N	N	N	N	N	N	N	3	C1, T12-L5
5237	N	N	N	N	N	N	N	1	N
5239	N	N. obs	N	N	Yes	N. obs	N	3	N
5241	N	N. obs	N	N	N	N	N	N	L3-5
5242	N	R-no;L-N. obs	N	N	N	N	N	N	N
5247	N	N	N	N. obs	N. obs	N	N	N. obs	N
5250	N	N	N	N	N	N. obs	N	N	Low T and L
5252	N	R-no;L-N. obs	N	N	N	N	N	N	N
5266	N	L-no; R-N. obs	N	N	N	Yes	N	N. obs	C and low T

Table 7.13 cont...

	5285	N	N	N	N	N	N	N	2	N
	5286	N	N	N	N	N	N	N	5	N
	5314	N	N. obs	N	N	N	N	N	2	T9
	5321	N	N	N	1	N	N	N	N	L4
	5363	N	N	N	3	N	N	N	3	N
	5371	N	N	L femoral head	2	N	N	N	N	N
	5094b	N	N	N	N	N	N	N	N	N

[a]MTT: 1[st] metatarsal; [b]MTT-phal. joint: metatarso-phalangeal joint

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarth
	5045	Poss 1	N	R lat fem-pat	N	N	N	N	N	T11-L5
	5062	Poss 1	N	L acetab*	4	N	N	N	3	T8-11, L3-5
	5119	Poss 1	N. obs	N. obs	3	N. obs	N. obs	N. obs	3	N
	5133	Poss 1	N. obs	N	N	N	N	N	1	N
	5150	Poss 1	N	N	1	N	N	N	N	L4-5
	5153	Poss 1	R-no;L-N. obs	N	N	N	N	N	N	C
	5009	Poss 2	N	N	N	N	N	N	1	Low T
	5098	Poss 2	N. obs	N	1	N	N	N	3+	T11-12
	5257	Poss 2	N	N	N. obs	N	N	N	N. obs	Low T
Raunds	5203	1	L-no; R-N. obs	N	4	N	N	N	N. obs	C5,7, L3-5
	5085	2	R and L	N	N	N	Yes	N	3+	L
	5087	2	N	N	3	N	N	N	N	N
	5118	2	N	N	N. obs	N	N	N	N. obs	L2 and L4
	5120	2	N	N	N	Prob	N	N	N. obs	T1, 3, 4, 10
	5155	2	N	N	N	N	N	N	N	N
	5186	2	N	L fem-pat	N	N	N	N	1	all verts
	5298	2	L-no; R-N. obs	N. obs	N	N	N. obs	N	N	C6-7, T12, L3-4
	5094a	2	N	N	1	N	N	N	N	L2 and L4
	5282	3	N	N	N	N	N	N	N	C

7.14 Pathologies observed in the early medieval Catalan individuals from Sant Esteve de Granollers and Sant Pere de Terrassa

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Sant Esteve de Granollers	9	N	N	N	1	N. obs	N	N	N	L4-5
	57	N	R-no;L-N. obs	N	N	N. obs	N	N	2	N
	60	N	N	N	N	N	N	N	1	N
	61	N	N	N	1	N	N	N	N	61
	72	N	N	N	2	N	N	N	N. obs	N
	76	N	N. obs	N	2	N	N. obs	N	1	T8-L5
	88	N	L-no; R-N. obs	N	N	N	N	N	N	N
	96	N	N	N	N. obs	N. obs	N	N	N. obs	T
	98	N	N. obs	N	N. obs	N	N	N	N. obs	T
	1074	N	N. obs	N. obs	N	N. obs	N. obs	N	N. obs	N
	1280	N	N. obs	N	N. obs	N. obs	N	N. obs	N. obs	N
	1318	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
	1625	N	N. obs	N	N	N. obs	N	N	N	N
	1704	N	N	N	N	N	N	N	N	N
	2072	N	N	N	N. obs	N. obs	N	N	N. obs	N
	2156	N	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	L
	2187	N	N. obs	N. obs	N. obs	N. obs	N. obs	N	N. obs	N
	2326	N	N	L MTT1	N. obs	N. obs	N	N	N. obs	T and L
Sant Pere de Terrassa	10	N	L-no;R-N. obs	N	N. obs	N. obs	Prob	N	N. obs	C6-7 and T
	30	N	N. obs	N	N	N	N	N	N. obs	N
	40	N	N	N	N	N	N	N	N	N
	49	N	N. obs	N	N	N	N	N	N	Yes
	60	N	N	N	N. obs	N	N	N	N. obs	Yes
	94	N	N	N	1	N. obs	N	N	N. obs	N
	95	N	N. obs	N	N	N. obs	N	N	N	N
	203	N	N. obs	N	N	N	N	N	N	N

Table 7.14 cont...

259	N	N	N	N	N	N	N	N	N
278	N	N	N	N. obs	N	N	N	N. obs	Yes
281	N	R-no;L-N. obs	R fem-tib, L fem-pat	N. obs	N. obs	N	N	N. obs	N
329	N	N. obs	N	1	N	N	N	N	L
345	N	N	N	N	N	Poss	N	N	N
368	N	N	N	N	N	N	N	N	Yes
388	N	N. obs	N	N	N	N	N	N	N
394	N	N	N. obs	N. obs	N. obs	N	N	N. obs	N
395	N	N. obs	N	N	N. obs	N	N	N. obs	N
405	N	N	N	1	N	N	N	N. obs	N
415	N	N	N	N	N	N	N	N	N
425	N	R-no;L-N. obs	N	N	N	N	N	N	N
432	N	N	N	1	N	N	N	2	N
533	N	N. obs	N	N	N	N	N	N	N
559	N	N. obs	N	7	N	N	N	N. obs	T11-12
635	N	N	N	1	N	N	N	N	N
655	N	N. obs	N	N	Poss	N	N	N	N
672	N	R-no;L-N. obs	L fem-tib	N	N	N	N	N	C5-6, L4-5
679	N	N	N	N	N	N	N	1	N
680	N	N	N	N	N	N	N	3+	N
682	N	N	N	1	N	N	N	N	N
690	N	N. obs	N	N	N	N	N	N	N
695.2	N	N	N	N. obs	N. obs	N	N	N. obs	N
704	N	N	N	N	N	N	N	N	L5
712	N	N	N	1	N	N	N	1	low T
753	N	N. obs	N	4	N	N	N	3+	N
755	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	all verts
769	N	N	N	N	N	N	N	N	N
771	N	N	N	N. obs	N	Prob	N	N. obs	C6-7, T9-12, L3-5
775	N	N. obs	N	N	N	N	N	1	Central - low T
778	N	N	N	N	N	N	N	N	N

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Sant Pere de Terrassa	6	Poss 1	R-no; L-N. obs	N	N	N	N	N	N	N
	670	Poss 1	R-no; L-N. obs	N	N	N	N	N	N	N
	697	Poss 1	L-no; R-N. obs	L tibia	2	N. obs	N	N	N. obs	all verts
	774	1	poss R/L	N	N	N	Yes	N	6	N
	365	2	N	N	1	N	N	N	N	N
	658	2	N	S. tali	3	N	N	N	N	low T
	713	3-4	R-no; L-N. obs	N	N	N. obs	N	N	N. obs	N
	480	4	N	N	N. obs	N	N	N	1	N

7.15 Pathologies observed in the late medieval English individuals of York Fishergate House

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
York Fishergate House	13	N	N	N	N	N	N	N	2	T and L
	21	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	T7-9, 12, L1
	27	N	N. obs	N	2	N	N	N	N	N
	29	N	N. obs	N	N. obs	N	N. obs	N	N. obs	N
	30	N	N	N	N	N	N	N	1	N
	31	N	N	R fem head	4	N. obs	N	N	N	yes
	39	N	N	N	N. obs	N. obs	Poss	N	N. obs	N
	40	N	N	R fem head	N	N	N	N	N. obs	C and L
	43	N	N	N	1	N. obs	N. obs	N	N	C
	44	N	N	N	N	Poss	N	N	N	N
	48	N	N. obs	N	N	N	N	N	N	C6-7, Low T and L
	49	N	N	N	2	N. obs	N	N	1	T5-T12
	50	N	L-no; R N. obs	N. obs	6	N	N	N	N	Low T and L
	52	N	N. obs	R?	1	N	N	N	N	Low T and L

Table 7.15 cont...

57	N	N	N	N	Prob	N	N	1	N
58	N	R-Yes, L-N. obs	N	N. obs	N. obs	N	N	N	C and L
60	N	N	N	N	N	N	N	1	Low T
61	N	N. obs	N	N	N	N	N	N	T9-L5
67	N	N	N	N	N	N	N	3	N
68	N	N	R 1st MTT	5	N	N	N	N	T and L
73	N	N	N	N	Prob	N	N	N. obs	T
76	N	N. obs	Nb	N. obs	N. obs	N. obs	N	1	N
77	N	N. obs	N	N. obs	N. obs	Poss.	N	N. obs	C6-T1
82	N	N. obs	N	1	N	N. obs	N	1	N
86	N	L-no; R N. obs	N	1	N	N	N	N. obs	all verts
87	N	N	N	1	N	N	N	N	L3
90	N	R-no; L-N. obs	N	N	N	N	N	N	N
94	N	N. obs	nN	N. obs	N. obs	N	N	N. obs	early T7-9
96	N	N	N	2	N	N	N	N	minimal C and T
98	N	N	N	N	N	N	N	1	N
101	N	L-Poss, R, no	N	3	N	N	N	2	Low T
110	N	N	R MTT1	N	N	N	N	2	C6-7, Low T and L
113	N	N	N	2	N	N	N	3+	T12
130	N	R-no; L-N. obs	N	3	N	N	N	N	C and L
131	N	N. obs	N	N	N. obs	N	N	1	N
136	N	N	N	1	N	N	N	N	N
155	N	N	N	N	N	N	N	1	v.early
159	N	N. obs	N	1	N	N	N	2	N
163	N	N	N	1	N	N	N	1	all verts
168	N	N	N	N	N	N	N	2	N
173	N	N	N	N	Yes	N	N	2	N
175	N	R-yes; L-poss	N	N. obs	N	N	N	N. obs	T11
186	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
204	N	N	N	3	N	N	N	N	T10-L5
209	N	N	N	1	N	N	N	N	N
219	N	N	N	1	N	N	N	3	N

Table 7.15 cont...

	251	N	R-no; L-N. obs	R MTT1	2	N	N	N	N	N
	259	N	N. obs	N	1	N	N	N	1	all verts
	260	N	N	N	N	N	N	N	1	N
	261	N	N. obs	N	N	N	N	N	N	N
	279	N	N	N	2	N. obs	N	N	2	N
	292	N	N. obs	N	N	N	N. obs	N	N	N
	296	N	R-no; L-N. obs	N	N	Yes	Prob	N	N	N
	309	N	R-poss; L-N.obs	N	N	N	N	N	N	L5
	310	N	N	N	N	N	N	N	N	N
	317	N	N	N	N. obs	N. obs	Poss	N	N. obs	T8

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
York Fishergate House	149	Poss 1	N	N	1	N	N	N	N	T12, L5
	84	Poss 2	N. obs	N	N	N. obs	N. obs	N	3	All verts
	62	2	N	N	1	N	Prob	N	1	N
	92	2	N. obs	N	N. obs	N. obs	N. obs	N. obs	N. obs	N
	172	2	N. obs	N	1	N	N	N	N. obs	All verts.
	28	4	R-N.obs; L-yes	N	4	N	N	N	1	C1-2, C6-t1
	120	4	N	N	N	N	N	N	N. obs	C5-T1, T4, 9, 12
	308	4	N	N	1	N	N	Poss	3+	T

7.16 Pathologies observed in the late medieval Catalan individuals of Sant Esteve de Canapost, Sant Miquel d'Olèrdola, Sant Pere de Terrassa and Vila-Sacra

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Sant Esteve de Canapost	60	N	N. obs	N. obs	N. obs	N. obs	N	N	N. obs	N
	61	N	N. obs	N	N	N	N. obs	N	N	N
	68	N	N. obs	R/L knee	2	N. obs	N. obs	N	N	Yes
	69	N	N. obs	N	N. obs	N. obs	N	N	N. obs	Yes
	79	N	N. obs	N	1	N	N	N	N	N
	87	N	N	N	N. obs	N. obs	N	N	N. obs	N
	95	N	R-no; L-N. obs	N	N. obs	N	N	N	N. obs	N
	99	N	N	N	N. obs	N. obs	N	N	N. obs	N
	140	N	N. obs	N	N	N	N. obs	N	N	Yes
	170	N	N	N	N	N. obs	Yes	N	N	N
	176	N	N. obs	N	3	N	N	N	N	N
	193	N	N	N	N	N. obs	N	N	N	N
	194	N	R-no; L-N. obs	N	N. obs	N. obs	N	N	N. obs	N
	197	N	N	N	4	N	N	N	3	N
	212	N	L-no; R-N. obs	N	1	N	N	N	N	N
	213	N	N	N	N. obs	N. obs	N	N	N. obs	Low T
	214	N	N. obs	N	N	N	N. obs	N. obs	N. obs	Low T + L
	206	N	N. obs	N	N	N	N. obs	N	N	N
	224	N	N	N	3	N	N	N	N	N
	228	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	N
	230	N	N. obs	N	N	N. obs	N. obs	N	2	N
	237	N	N	N	N	N	Poss	N	2	N
	242	N	R-no; L-N. obs	N	N. obs	N. obs	N. obs	N	N. obs	L
	265	N	N. obs	N	N. obs	N. obs	N. obs	N. obs	N. obs	N
	270	N	N. obs	N. obs	N. obs	N	N	N	N. obs	L
	271	N	N	N. obs	N	N. obs	N. obs	N	N. obs	L

Table 7.16 cont...

	276	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	N
	286	N	R and L	N	N. obs	N	N	N	N. obs	Low T + L
	297	N	N	N	N. obs	N. obs	N. obs	N	N. obs	T and L
	1054	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
Sant Miquel d'Olèrdola	10	n	R-no; L-N. obs	N	2	N	N	N	N	T7-9
	18	n	L-no; R-Poss	N	N	N	N	N	N	N
	27	n	R-no; L-N. obs	N	N	N	N	N	N	N
	44	n	N. obs	N	1	N	N	N	N	T and L
	59	n	N. obs	N	N	N	N. obs	N	N	N
	67	n	N. obs	N	1	N	N	N	N	N
	72	n	N	N	N. obs	N	N	N	N. obs	N
	73	n	R-no; L-N. obs	N	N. obs	N. obs	N	N	N. obs	N
	38a	n	N. obs	N	N	N	N. obs	N	N	N
Sant Pere de Terrassa	228	n	N. obs	R/L lat condyle femur	N. obs	N	N	N	N. obs	Yes
	261	n	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
	265	n	N. obs	N	N	N	N	N	N	N
	611	n	N	N	N. obs	N	N	N	N. obs	N
	612	n	N	N	4	N	N	N	N	N
	613	n	N	N	N	N	N	N	N. obs	N
	627	n	N	N. obs	N	N. obs	N. obs	N	1	Yes
	660	n	N. obs	N. obs	3	N	N. obs	N. obs	1	N
	685	n	Poss R	L knee	1	N	N	N	N	Yes
	756	n	N	N	1	N	N	N	N	N
	770	n	N	N	N	N	N	N	N. obs	T
Vila-Sacra	6	N	N. obs	N	1	N. obs	N. obs	N	1	N
	8	N	N	N	3	N	N	N	N	L
	16	N	N	N	N. obs	N. obs	N	N	N. obs	N
	18	N	N. obs	N	N. obs	N. obs	N. obs	N. obs	N. obs	L
	19	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
	34	N	N. obs	N. obs	N	N. obs	N. obs	N	N	N
	35	N	N. obs	N	N	N. obs	N	N	N	N
	38	N	N	N	N. obs	N. obs	N	N	N. obs	N

Table 7.16 cont...

44	N	N	N	1	N	N	N	2	N
52	N	N. obs	N	N	N. obs	N	N	N	N
53	N	N. obs	N	N. obs	N. obs	N. obs	N	N. obs	N
54	N	N	N	N	N	N	N	3+	N
63	N	N. obs	N	N. obs	N. obs	N	N	N	N
68	N	L-no; R-N. obs	N	3	N	N	N	1	N
77	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N
80	N	L-no; R-N. obs	N	N	N. obs	N	N	2	N
84	N	N. obs	N	N. obs	N	N	N	N. obs	C and L
85	N	N. obs	N	N	N	N. obs	N	N	N
89	N	N. obs	N. obs	2	N	N. obs	N	6	N
90	N	R-no; L-N. obs	N	N. obs	N. obs	N	N	N. obs	N
91	N	N	N	N. obs	N. obs	N	N	N	N
92	N	N	N	N. obs	N. obs	N	N	N. obs	N
96	N	N. obs	N	1	N	N. obs	N	N	N
98	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
100	N	N	N	N	N	N	N	N	N
104	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N
106	N	N. obs	N	2	N	N	N	2	N
107	N	N	N	1	Poss	N	N	3	N
109	N	N	N	N	N	N	N	N	N
115	N	N. obs	N	N	N	N	N	N	Yes
138	N	N. obs	N	N. obs	N. obs	N	N	N. obs	N

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Can	274	Poss 1	N	N	N	N	N	N	N	T12 and L
Ter	288	Poss 1	N	N. obs	N. obs	N. obs	N. obs	N	N. obs	N
Ol	68	Poss 2	L-no; R-N. obs	N	N	N	N	N	N	N
Vil	66	Poss 3	N. obs	N	N	N	N	N	2	T11
Ter	619	2	N	N	N. obs	N. obs	N	N	N	mild
Ter	632	2	N	N	N. obs	N. obs	N	N	N. obs	Low T and L
Can	279	3	n	N	1	N	N	N	N	N
Vil	99	3	N. obs	N	N. obs	N. obs	N	N	N. obs	N

7.17 Pathologies observed in the post-medieval English individuals from Wolverhampton

Individuals without DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
	HB28	N	N	N	N. obs	N	N	N	N. obs	N
	HB35	N	N. obs	N	2	prob	N. obs	N	N	N
	HB43	N	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	N. obs	T9-10, L
	HB44	N	N. obs	N	N	N	N	N	7	N
	HB46	N	N	N	N. obs	N	prob	N	3	N
	HB53	N	N. obs	N	12	N	Poss	N	N	N
	HB54	N	N. obs	N	2	Poss	N	N	4	L
Wolverhampton	HB56	N	N	N	2	prob	N	N	N	N
	HB61	N	N. obs	N	7	N	N	N	2	N
	HB62	N	N. obs	N	2	Yes	N	N	N	N
	HB70	N	N	N	3	N	N	N	1	N
	HB76	N	N. obs	L fem knee	N. obs	N	N	N	N. obs	Yes
	HB88	N	N. obs	N. obs	3	N	N. obs	N	7	N
	HB90	N	N. obs	N	1	N	N	N	2	N
	HB96	N	N. obs	N	1	N	N	N	1	N

Table 7.17 cont...

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
	HB97	N	N. obs	N	1	N. obs	N. obs	N	N	N
	HB98	N	L-no; R-N. obs	N	N. obs	N. obs	Poss	N	N. obs	N
	HB109	N	N. obs	N	1	N	N	N	N	Low T
	HB111	N	N	N	4	N	Poss	N	3+	N
	HB116	N	N. obs	N	2	N	N	N	N	N
	HB117	N	N. obs	N	3	N	N	N	1	N
	HB118	N	N. obs	N	2	Prob	N	N	4	N
	HB124	N	N. obs	R arm	N	N	N. obs	N	N. obs	T12
	HB125	N	N. obs	N	N	N	N	N	3	N
	HB128	N	N. obs	N	N. obs	N. obs	N	N	N. obs	Yes

Individuals with DISH

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Wolverhampton	HB36	Poss 1	N	L acet/fem head, L distal phal.	N. obs	N	Prob	N	N. obs	L
	HB39	4	N. obs	no	N. obs	N	N	N	1	N

7.18 Pathologies observed in the post-medieval Catalan individuals from Sant Esteve de Canapost

Site	Ind.	DISH	Gout	OA	CL	Scurvy	Rickets	Osteom.	LEH	Discarthr.
Sant Esteve de Canapost	7	N	R-Poss, L-no	no	1	N. obs	N	N	N. obs	N
	38	N	N	no	N. obs	N. obs	N	N	N. obs	all verts
	44	N	N. obs	no	N. obs	N. obs	N	N	N. obs	N
	58	N	N. obs	no	N	N	N	N	N	N
	73	N	L-Yes, R-no	no	N. obs	N. obs	Poss	N	N. obs	N
	102	N	N. obs	no	N. obs	N. obs	N. obs	N	N. obs	C

Appendix 8: Results Part B.5.11: Supporting tables.

8.1 Cattle and sheep/goat isotope data obtained from Romano-British sites published literature of DISH development

Source	Period	Species	δ13C ‰	δ15N ‰
Redfern et al. 2010	Romano-British	Cattle	-21.4	6.2
		Sheep	-21.3	4.9
Chenery et al. 2011	Romano-British	Cattle	-21.6	5.7
		Sheep/goat	-21.6	5.7
Chenery et al. 2010	Romano-British	Cattle	-21.7	6.5
		Sheep/goat	-21.4	5.4
Lightfood et al. 2009	Romano-British	Cattle	-21.5	6.7
		Sheep/goat	-21.4	7.6
Average		**Cattle**	**-21.6**	**6.1**
		Sheep	**-21.5**	**6.1**
		Combined	**-21.55**	**6.12**

8.2 Cattle, pig and sheep/goat isotope data obtained from other Spanish and Mediterranean Roman sites published literature of DISH development

Source	Region	Period	Species	$\delta^{13}C$ ‰	$\delta^{15}N$ ‰
López-Costas and Müldner 2016	A Lanzada, Galícia	Roman	Cattle	-20.4±0.9	7.1±1.5
			Sheep/goat	-19.9±0.6	7.5±1.6
			Pig	-18.9±2.4	9.5±1.9
Garcia et al. 2004	Mallorca	Late Roman	Cattle	-21.0	6.0
			Sheep/goat	-20.6	6.5
			Pig	-21.2	5.0
Lightfoot et al. 2012	Croacia	Late Roman	Cattle	-20.4	4.4±0.7
			Sheep/goat	-20.6	4.8±1.0
			Pig	-20.3	6.4±1.5
Rissech et al. 2016	Barcelona	Roman (1st-4th AD)	Cattle	-21.3±0.7	2.7±0.8
			Sheep/goat	-20.5±0.2	5.1±1.1
			Pig	-19.9±0.5	6.5±2.2
Prowse et al. 2004	Isola Sacra	Imperial Rome	Cattle	-20.7±0.8	5.2±1.6
			Sheep/goat	-20.9±0.4	5.8
			Pig	-21.0±1.4	5.2±1.7
Keenleyside et al. 2009	Leptiminus - Tunisia	Roman and Late Roman	Cattle	-18.8	10.3
			Sheep/goat	-19.1	6.0
			Sheep (SA)	-20.5	11.7
			Goat	-18.3	6.2
			Pig	-19.0	9.6
Craig et al. 2009	Velia - Italy	Imperial Rome	Cattle	-22.6	2.9
			Sheep/goat	-20.2	4.6
			Pig	-21.0±0.4	4.7±2.0
Average	**Mediterranean area**	**Roman**	**Cattle**	**-20.8**	**5.5**
			Sheep/goat	**-20.0**	**5.8**
			Pig	**-20.2**	**6.7**
			Combined	**-20.4**	**6.0**